Biological and physico-chemical status of two wetlands in the Nairobi National Park, Kenya

by

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DECLARATION

I, William Kipchirchir Samoei Ruto, hereby declare that this is my original work and has not been presented for a degree in any other university to the best of my knowledge.

Signed..... Date 18/08/2011

This thesis has been submitted for examination with our approval as university supervisors:

	Signature	Date
1. Prof. Jenesio I. Kinyamario		18/8/2011
2. Dr. John K. Mworia		18/8/2011
3. Dr. Elijah Akunda		18/08/2011

DEDICATION

This thesis is dedicated to my wife Rachel for helping me bring up my children June, Nicholas, Charlene, Stephanie, George and Cullie and to my constituents of Eldoret North for their understanding. Their love, prayers and wishes have helped me realize this momentous academic goal.

ACKNOWLEDGEMENTS

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God Bless You All

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ABSTRACT

A wetland is an area of land whose soil is saturated with moisture either permanently or seasonally. Such areas may also be covered partially or completely by shallow pools of water. Wetlands include swamps, marshes, and bogs, among others. Wetlands differ in their soils, landscapes, microclimates, water regimes and chemistry, vegetation types, and human disturbances. Chemical composition of wetlands varies depending on their location, substrate chemistry, the amount of water present in them and human impacts. These variations have corresponding impacts on the aquatic biota of the ecosystems. Challenges facing the ecological integrity of wetland ecosystems vary but are mostly affected by overexploitation, changes in water quality, eutrophication, organic loading, invasive species, and hydrographic changes in aquatic systems. These challenges can be traced to changes in land use patterns or anthropogenic activities, waste disposal, and diversions or impoundments of water bodies feeding these systems. Two wetlands (Hyena and Nalogomon dams) in the Nairobi National Park were studied. These wetlands are important providers of ecosystem goods and services such as drinking water and dry season grazing habitat for wild game in the park. The main objective of this study was to determine the environmental status of the two wetlands by comparing their physico-chemical properties of their water and soil/sediment; and to document the plant species diversity of their immediate environments. Four points were selected randomly in each dam site. Three samples of both water and soil were collected from each point and taken to the lab for analysis.

There were significant ($p < 0.05$) differences in phosphorus, magnesium, copper and sulphates in soil/sediment between Hyena and Nalogomon study sites. Soils/sediment at Hyena had the highest levels of heavy metals, especially copper (4.73 ± 0.05 mg/kg), compared to Nalogomon. Likewise, there were differences in water parameters, namely manganese and sulphates were found to be significantly ($p < 0.05$) higher at Hyena than at Nalogomon. Plant tissues at Hyena Dam were found to have higher levels of iron (0.63 ± 0.12 mg/kg) compared to those of Nalogomon (0.47 ± 0.09 mg/kg). The most common plant species at Hyena was *Cyperus dives* while at Nalogomon were *Typha domingensis* and *Hyparrhemia rufa*. Generally it was concluded that Hyena had more pollutants due to human effects compared to Nalogomon. This shows that conservation measures should be taken to control pollution of wetlands in Nairobi National park especially the pollution coming from the human estates nearby.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.0 Introduction

A wetland is an area of land whose soil is saturated with moisture either permanently or seasonally (Mitsch and Gosselink, 2007). Such areas may also be covered partially of completely by shallow pools of water. The water can be salty, fresh, or brackish. They are generally distinguished from other water bodies based on their water level and on the types of plants that thrive within them. Specifically, wetlands are characterized as having a water table that stands at or near the land surface for a long enough period each year to support aquatic plants.

Wetlands differ in their soils, landscape, climate, water regime and chemistry, vegetation, and human disturbance (Whigham and Verhoeven, 2009). Generally wetlands are classified into two general categories: marshes and swamps. Marshes are defined as wetlands frequently or continually inundated with water, characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions. All types of marshes receive most of their water from surface sources, although some are also fed by groundwater (Terry, 2009). Marshes are further characterized as salt or brackish and freshwater marshes. Salt or brackish marshes are the most prevalent types of tidal marshes and are characterized by salt tolerant plants/halophytes such as mangroves on the Kenyan coast. Freshwater marshes are characterized by periodic or permanent inundation of shallow water and with little or no peat deposition. They typically derive most of their water from surface waters, including floodwater and runoff but they too

may receive ground water inputs.

A swamp is a wetland featuring temporary or permanent flooding of large areas of land by shallow bodies of water. A swamp generally has a substantial number of hammocks, or dry-land protrusions, covered by aquatic vegetation, or vegetation that tolerates periodical inundation. In Africa swamps are normally dominated by herbaceous vegetation (Howard-Williams and Gaudet, 1985). Swamps are fed primarily by surface water inputs and they occur in either freshwater or salt water floodplains (Harper *et al.*, 1999). They are characterized by very wet soils during the dry season and standing water during rainy season. In Kenya, such swamps are found around Lake Victoria, Yala and Lake Naivasha.

1.1 Literature Review

1.1.1 Physico-chemical environment of wetlands

Changes in water quality can alter the whole wetland ecosystem, including fauna species around it. Aquatic organisms are sensitive to changes in the physico-chemical properties of the water they live in (Brix and Schierup, 1989). Water quality is considered degraded when physico-chemical conditions change so that many types of resident organisms are negatively affected.

The major driving forces controlling the physical composition of the aquatic environments are rainfall, erosion and chemical solution, evaporation and sedimentation (Goldman and Horn, 1983; Burgis and Morris, 1987). Major physical factors that usually affect the wetlands significantly are; temperature, pH, electrical conductivity, dissolved oxygen, mineral nutrients and water depth

(Boney, 1989). Among these factors, variations in temperature usually have the most profound (and sometimes lethal) effects on the living aquatic resources. They have a direct influence on the biological functions of plants and animals (Lickens, 1975; Burgis and Morris, 1987; Boney, 1989) especially in deep water bodies.

1.1.2 Water temperature

Water temperature determines the density of the water hence the nature of stratification especially in large water bodies with depths more than 10 m (Burgis and Morris, 1987). Temperature affects the rates of chemical and biological processes. It also affects the oxygen concentration in water, the metabolic rates of aquatic plants and the sensitivity of aquatic organisms to toxic stresses.

1.1.3 Water pH

The pH of water determines the solubility and biological availability of chemical constituents such as nutrients, for example phosphorus, nitrogen, potassium, sulphur and carbon; and heavy metals for example lead, copper, and cadmium (Gaudet, 1979). In addition to, for instance, affecting how much and what form of phosphorus is most abundant in the water, pH also determines whether aquatic life can use the water body. Metals tend to be more toxic at lower pH because they are more soluble. Small changes in pH are not likely to have a significant impact on aquatic life but they influence the availability and solubility of all chemical forms and may aggravate nutrient problems (Gaudet, 1979). The level

of acidity can be changed by human's activities. Acid rain, a result of air pollution, affects pH in wetlands. Other pollutants carried by runoff from land also change the acidity of the water. pH values between 7.0 and 8.0 which are optimal for supporting a diverse aquatic ecosystem (Gaudet, 1979).

1.1.4 Electrical conductivity

Electrical conductivity is a measure of the amount of dissolved ions in water and the higher the concentration, the higher the conductivity of water. Conductivity is also affected by temperature and the warmer the water the higher the conductivity. Environmental conditions such as drought, changing seasons and heavy rainfall among others can also cause the concentration of dissolved ions in water to vary significantly. In general, fresh waters are more productive except where nutrients or environmental factors are limiting. High levels of mineral salts in freshwater can directly affect plant growth by influencing their ion regulation and osmotic stress.

1.1.5 Dissolved oxygen

Dissolved oxygen is a critical aspect of water quality indicating the health of an aquatic system because aquatic organisms need oxygen to survive. The amount of dissolved oxygen in water is a critical factor that determines the species and abundance of species that can live in a water body (Kimirei *et al.*, 2005). Dissolved oxygen levels are influenced by temperature and salinity, which are in turn influenced by climatic and geological dynamics respectively. The solubility

of oxygen, or its ability to dissolve in water, decreases with increasing temperature and salinity. Aquatic macrophytes are able to extract dissolved oxygen from the water medium with the optimum level of dissolved oxygen being around 9 mg/l (Kalff and Knoechel, 2002).

1.1.6 Mineral nutrients

Water moving into a wetland has to run over rocks or soil in the catchment area, dissolving out chemicals including salts on its way. The salts dissolve in the water forming ions some of which are positively charged (cations) such as Na^{+}, Ca^{2+} and Mg^{2+} or negatively charged (anions) such as CO_3^{-} SO_4^{2-} and NO_3^{-} (Weirich *et al.*, 2005). The total amounts of ions dissolved in water may be measured as electrical conductivity (EC) (Burgis and Morris, 1987). Water entering wetlands also contains hydrogen ions. Lower pH indicates acidity while higher pH indicates alkalinity. Swamps which receive water that has flowed over or through rocks or soils rich in carbonate ions have high pH depending on the rock composition or composition of the effluent discharged into the water.

Studies on the chemical composition have been done on various wetlands in Kenya, primarily on Lake Naivasha (Gaudet, 1979; Muthuri *et al.*, 1989; Harper *et al.*, 1999) Yala (Abila *et al.*, 2008) Saiwa and Nyando (Raburu, 2003; Abila *et al.*, 2005; Owino and Ryan, 2007; Obiero, 2009). Most of these studies have revealed that chemical composition of the wetlands vary depending on their location (Muthuri and Jones, 1997; Keddy and Frazer, 2000), geology (Masese *et al.*, 2008; Okoth *et al.*, 2009), human impacts on the catchments (Raburu,

2003) as well as amount of water present (Raburu, 2003; Ssegawa *et al.*, 2004; Abila *et al.*, 2005). These have corresponding impacts on the aquatic biota of the ecosystems.

Mineral nutrients are an important chemical factor in wetland ecosystems (Hutchinson, 1975; Moss, 1980; Goldman and Horn, 1983; Burgis and Morris, 1987; Haven *et al.*, 2001; McCartney *et al.*, 2005). The most important nutrients are those that are often short in supply and limit growth of plants (Almazan and Boyd, 1978; Downing, 1999). Both nitrogen and phosphorus are essential to life processes (Reynolds, 1984) but while there are many sources of nitrogen, phosphorus is often in short supply and therefore limiting to plant growth (Hecky and Kilham, 1973; Moss, 1980; Goldman and Horn, 1983; Burgis and Morris, 1987). Downing (1999) and Kalff and Snoechel (2002) suggested that although nitrogen was usually abundant in temperate regions, it could be a limiting nutrient in a number of tropical ecosystems. Limnological studies done in a number of tropical wetlands usually indicate that nitrogen, phosphorus or both limit aquatic primary production (Mellack *et al.*, 1982; Njuguna, 1982; Kitaka, 1991).

1.1.7 Plant species composition and diversity

Studies on wetland vegetation community structure and the role of environmental change are fundamental step towards redefining these ecosystems. Each wetland has its own unique species community structure that is subjected to changes (Harper *et al.*, 1999; Ashley *et al.*, 2002; Ssegawa *et al.*, 2004). Although high

diversity in plant species composition have been recorded in various swamps (Beadle, 1974; Owen, 1992; Grytnes *et al.,* 2006; Rainbow, 2007; Janousek, 2009), many African swamps are characterized by tropical species *Phragmites, Typha*, and many species of *Cyperus* (Gaudet, 1979; Muthuri *et al.,* 1989; Harper *et al.,* 1999; Owino and Ryan, 2007).

The diversity of plant species within a plant community reflects the complexity in the physical, chemical and human environment (Sundt-Hansen *et al.,* 2006; Whittaker, 2006; Moss, 2008). Gichuki *et al.* (2001) showed that there are strong relationships between environmental quality and vegetation composition and abundance with strong coupling effects being in those areas that are prone to anthropogenic disturbances in the catchment.

A number of authors have highlighted environmental change as the major driving force in regulating plant species composition in wetlands (Tailing and Tailing, 1965; Tekeuchi, 2005; Abila *et al.,* 2008; Stumm e*t al.,* 2009). Adaptations to changing environment with phases of fluctuating events can subject a plant community to dominance by the most competitive species. Van Mooy *et al.* (2006) have shown that species diversity of wetlands can be affected by environmental disturbances to a point where the habitat is dominated by a few species.

Some studies have shown that human factors have a very fundamental influence over plant species composition of wetland environments (Allen *et al.,* 2005; Abila *et al.,* 2008). In many wetlands, human activities have been found to fundamentally alter the structure of the eukaryotic and prokaryotic community

(Chapman *et al.*, 2001). Burns and Schallenberg (2001) observed that agriculture, fire and livestock grazing in wetlands may lower species diversity. Habitat influence by man such as clearing land for cultivation, construction of settlements or draining wetlands degrades the habitat and can cause local extinction of some species, thus reducing habitat species diversity (Primack, 1993).

1.1.8 Primary productivity of wetlands

The flow of energy through any ecosystem starts with the fixation of carbon dioxide using solar energy by plants and other autotrophic organisms. In this way plant accumulates organic matter forming primary production.

The importance of primary production in aquatic ecosystems has been studied in many areas (Kallquist, 1978; Vareschi, 1982; Boyd, 1990; Knud-Hassen *et al.*, 1994; Blomqvist, 2001; Ram *et al.*, 2006). Primary production is usually very high in eutrophic systems (Vareschi, 1982; Moss, 2008). A few highly specialized plants pre-dominate primary production in most of these aquatic ecosystems (Tailing and Tailing, 1965; Moss, 1980; Vareschi, 1982; Muthuri *et al.*, 1989).

In general, wetlands have some of the highest primary production of all the world's ecosystems (Thompson and Hamilton, 1983). Tropical wetlands are some of the most productive tropical ecosystems because they have water for most of the year, and are dominated by a single vigorous species so that little energy is used in competition with other species (Moss, 1988). Primary

production of papyrus (*Cyperus papyrus*) in a tropical wetland around Lake Naivasha, Kenya, was reported to be 14.1 g m^{-2} day^{-1} (Muthuri and Jones, 1997). The ability of wetlands to self sustain themselves has been linked to their levels of primary production and biogeochemical cycling of nutrients.

1.1.9 Conservation Status of wetlands

Rapid human population growth, industrialization and urbanization largely contribute to loss and unsustainable use of wetlands worldwide (Abila *et al.*, 2005). Expanding industries and urban centres discharge their waste water into the neighbouring wetlands, hence causing pollution. Most of the Kenya's wetlands had been degraded (Mironga, 2005a) while some have already disappeared (Mironga, 2005a, 2005b). This has resulted in reduction and loss of habitats and subsequent loss of many useful plants and animals dependent on the wetlands. The major threats facing the conservation of wetlands in Kenya are human encroachment and settlement (Chapman *et al.*, 2001).

The Ramsar Convention, also known as the Convention on Conservation of Waterfowl and Waterfowl Habitats, was signed in the city of Ramsar in Iran in the year 1971. Kenya is signatory to the Ramsar Convention having ratified the treaty in 1974. The convention requires member parties to declare several wetland areas as Ramsar conservation areas and to prepare for them wetland management plans. The parties to the Convention will apply guidelines that have been put out by the Convention for the conservation of such wetlands. In Kenya, such Ramsar sites include lakes Baringo, Bogoria, Elmenteita, Naivasha and Nakuru. This convention plays an important role

in facilitating the protection of wetlands of international significance. However, the full protection of the remaining wetlands in Kenya can only be achieved through implementation of management strategies at national and regional levels.

In Kenya, wetlands are patchy and localized (Britton, 1978; Bennun and Njoroge, 1999; Boar *et al.*, 1999) and despite being important and highly productive habitats, few Kenyan wetlands are formally protected (Bennun and Njoroge, 1999). Human encroachment is a major challenge for conservation of wetlands in Kenya. Challenges facing the ecological integrity of wetlands vary but are mostly affected by changes in water quality, eutrophication, organic loading, and invasive species and pollution (Hemond and Benoit, 1998; Haven *et al.*, 2001).

Land use activities around wetlands in Nairobi National Park are dominated by wildlife grazing and human urban settlements. These activities have intensified in recent years and are of particular concern as they have led to other forms of disturbance to wetlands such as pollution and aquatic weeds proliferation (van der Weghe, 1981; Mafabi, 2000).

Wetlands are of vital ecological importance in the Nairobi National Park where they provide vital ecosystem goods and services to the biodiversity that occurs there. Limitations on knowledge of physico-chemical characteristics of the wetlands in Nairobi National Park ultimately impair their management. Therefore, a study on status of water quality, biodiversity and threats to the wetlands could avert serious ecological damages to these wetlands and associated ecosystems. However, no previous ecological studies on these wetlands in the

Nairobi National Park have been carried out.

1.1.10 General objective of the study

The main objective of this study was to determine the environmental status of two wetlands in the Nairobi National Park, namely Nalogomon and Hyena dams study sites.

1.1.10.1 Specific objectives of the study

Specific objectives of the study were as follows:

1. To determine the water quality of the two wetlands.
2. To compare the soil/sediment chemical composition of the wetlands.
3. To document the plant species diversity of the two wetlands
4. To determine possible human impacts on the wetlands due to urban settlements.

CHAPTER 2: MATERIALS AND METHODS

2.0 Study Area

Nairobi National Park, where the study was conducted, was established in 1946 as Kenya's first national park. The park covers about 117 km^2 at an altitude of between 1,540 and 1,780 m. The climate is tropical monsoon with two rain seasons from October to December and from March to June and is governed by the Inter-tropical Convergence Zone (ITCZ). Rainfall averages about 1000 mm per annum. The geology of the study area forms part of the Ngong Hills catchment that is underlain by tertiary volcanic rocks, namely, Ngong basalts, Ol Doinyo Narok agglomerate, Limuru quartz trachyte, Kerichwa valley tuff, Nairobi trachyte, Nairobi phonolite, Mbagathi trachyte, Kandizi phonolite and Ol Esayeti phonolite (Saggerson, 1991). These volcanic minerals are often rich in primary mineral elements such as iron, manganese, zinc and copper unlike those derived from igneous rocks of the basement system. The volcanic rocks are associated with the numerous volcanic activities along the Kenya rift valley (Saggerson, 1991). The soils in the park range from volcanic nitisols (rich in sesquioxides of iron, manganese and aluminium) in the northern parts occupied by dry land forest to black cotton vertisols in much of the southern parts of the park occupied by grasslands.

The vegetation of the park consists mainly of open grass plains dominated by *Themeda triandra* - scattered Acacia grassland while part of the northern area is covered by highland dry forest. The park is also dissected by several streams that have been impounded to make dams to provide water to animals and are bounded by riparian forests especially in the southern boundary. Around these dam sites, wetlands have also formed,

for example at the Nalogomon and Hyena dams (Figs.1, 2 and 3). The park is part of a much larger ecosystem (the Athi Kapiti Plains) and home to a wide range of fauna and flora. The animals found in the park include black rhinoceros, lion, leopard, hyena, cheetah, buffalo, eland, wildebeest, zebra, hippopotamus, giraffe, and diverse birdlife. The most dominant wildlife herbivores are wildebeest *Connochaetes taurinus*, Buchell's zebra *Equus burchelli*. Others include Grant's gazelle *Gazella grantii*, and Thomson's gazelles *Gazella thomsoni*, Coke's Hartebeest *Alcelaphus buselaphus cokii*, warthog *Phacochoerus aethiopicus*, Cape eland *Taurotragus oryx*, waterbuck, *kobus ellipsiprymnus*, impala *Aepyceros melampus*, Maasai giraffe *Giraffa camelopardalis tippelskirchi*, buffalo *Syncerus caffer*, reedbuck *Redunca redunca*, bushbuck *Tragelaphus scriptus*, leopard *Panthera pardus*, lion *Panthera leo*, spotted hyena *Crocuta crocuta*, black backed jackal *canis mesomelas*, and bat eared foxes *Otocyon megalotis*.

This study was conducted at two wetlands located around Nalogomon and Hyena dams, in Nairobi National Park, Kenya. The dams are located about 2.4 km distance from each other and are fed by separate water sources (Fig. 1). Plates 1 and 2 show the general vegetation of the two study sites. At Nalogomon Dam the vegetation is dominated by *Typha domingensis, Hyparrhenia rufa* and *Themeda triandra* while at Hyena Dam the vegetation is dominated by *Cyperus dives*, some *Typha dominfensis*, and floating macrophytes (*Gunnera perpensa, Enhydra fluctuans and Ludwigia abyssinica*). The animal species found around the two dams included the Nile crocodile *Crocodylus niloticus*, hippopotamus *Hippopotamus amphibius*, various waterfowls, warthogs and various kinds of gazelles.

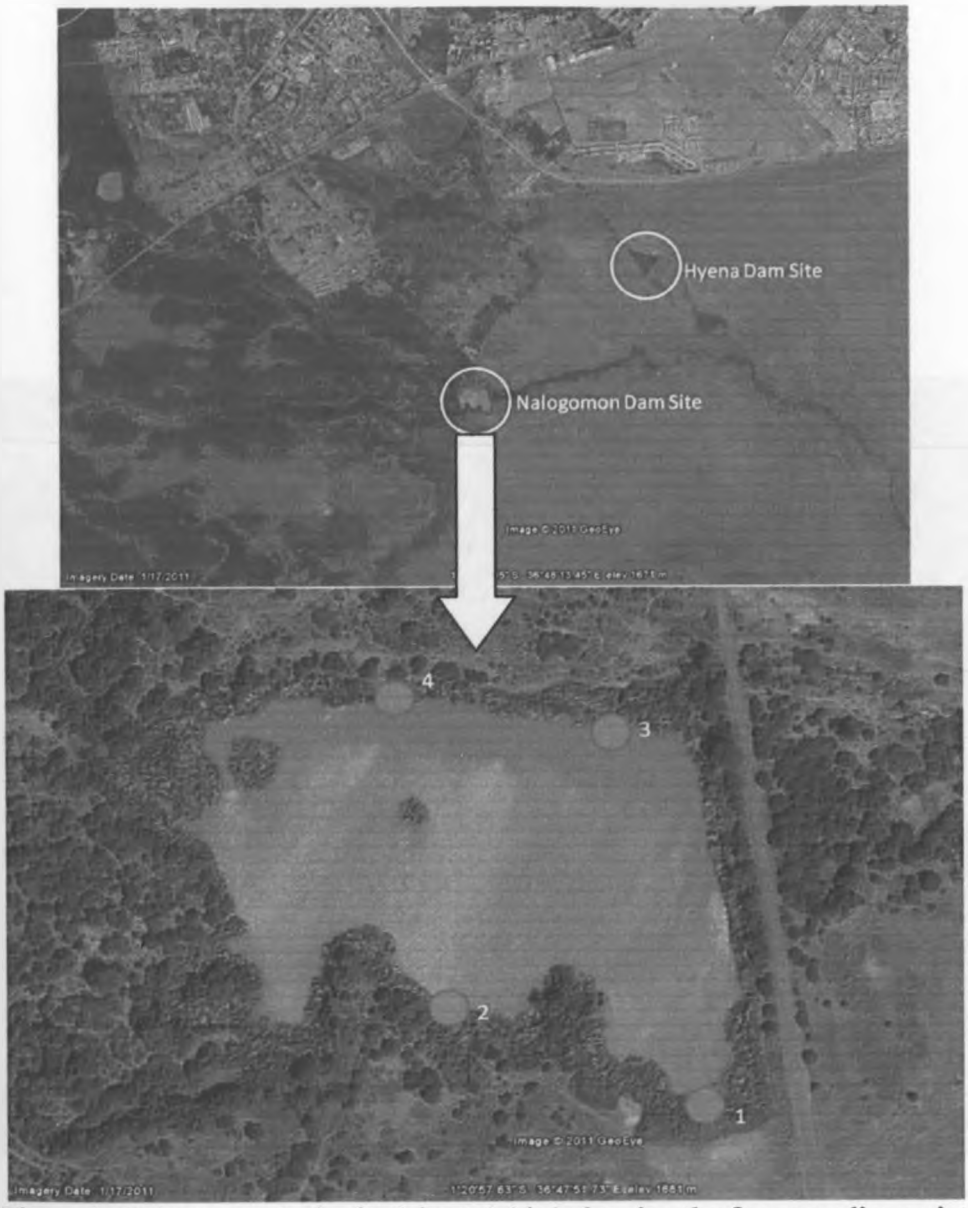

Figure 1: Nalogomon study site (about 4.4 ha) showing the four sampling points.

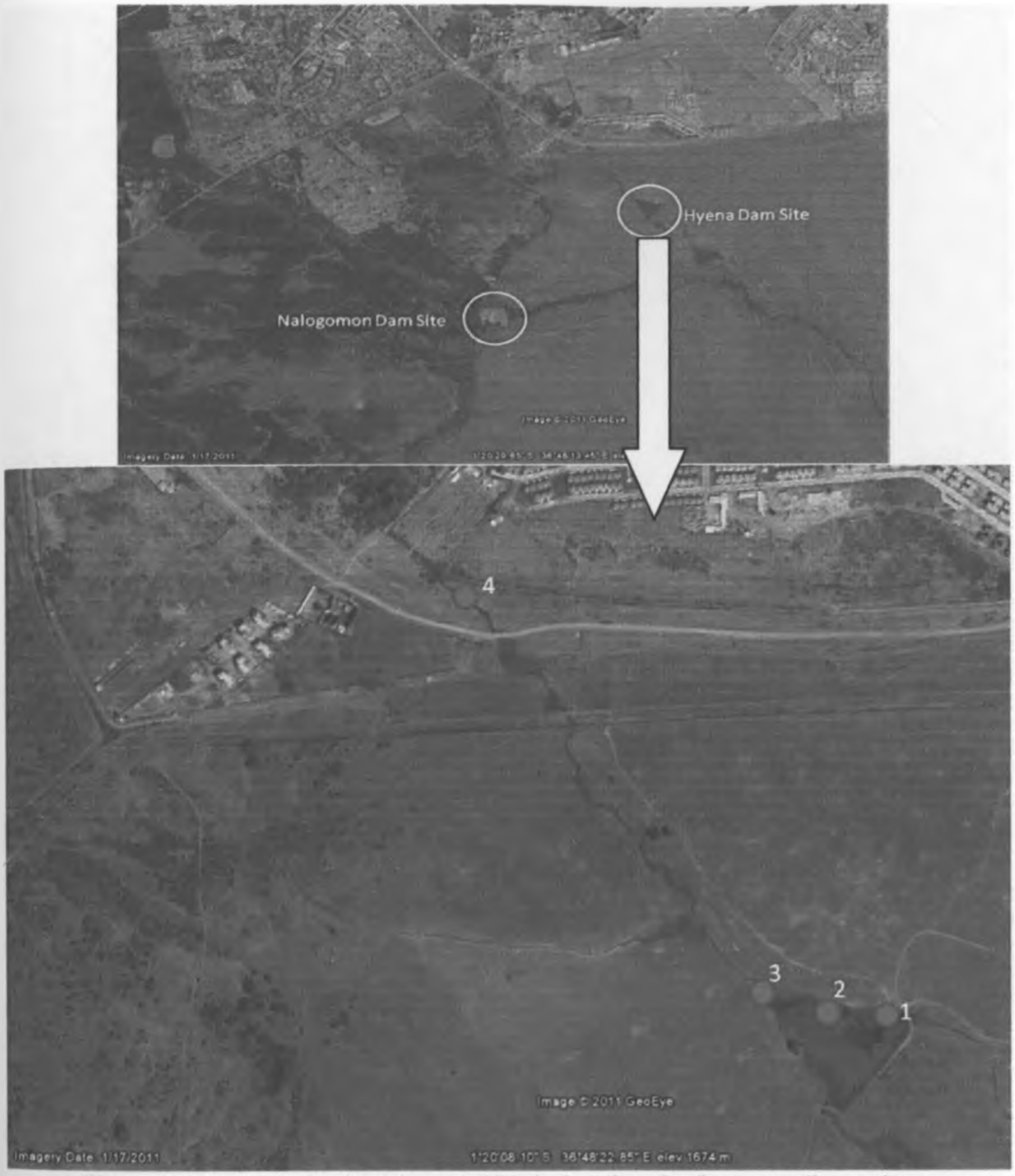

Figure 2: Hyena study site (about 1.75 ha) showing the four sampling points.

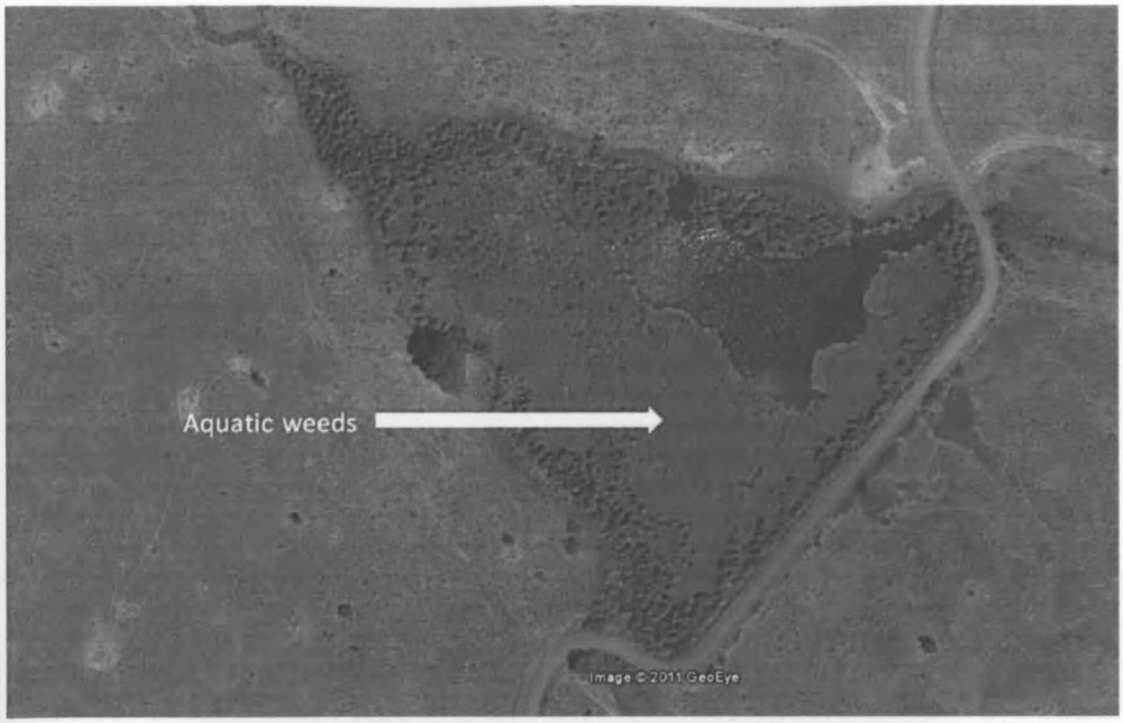

Figure 3: Hyena Dam (in contrast to Nalogomon Dam, shows that it is heavily infested with aquatic weeds that cover nearly 65% of the water surface).

2.1 Sampling Regime

Samples of water and soil/sediments were collected from four points at each wetland at intervals of two weeks during the dry and wet season over a four month period starting in February and ending in May 2011. Using a grid, four sampling points for Nalogomon Dam study site were selected randomly, while for Hyena Dam study site three points were selected along the northern side (due to accessibility of the dam water). The fourth point was selected some 750 m up the dam and 300 m to the nearest buildings (the Carnivore Hotel and Restaurant) along the water channel. This point was to gauge the influence of human urban activities on the quality of water flowing into the dam. Twelve samples of soil/sediments were collected at a depth of 15 cm using a hand auger per dam and

kept in labelled soil/sediment bags. The soil/sediment bags were stored in cool boxes kept at around 0 °C using ice-cubes and transported to the laboratory for chemical analysis. Three water samples were also collected at four sampling points per site as described above (12 samples per study site). Plant samples for tissue element analysis were also collected from the four sampling points at each dam study site.

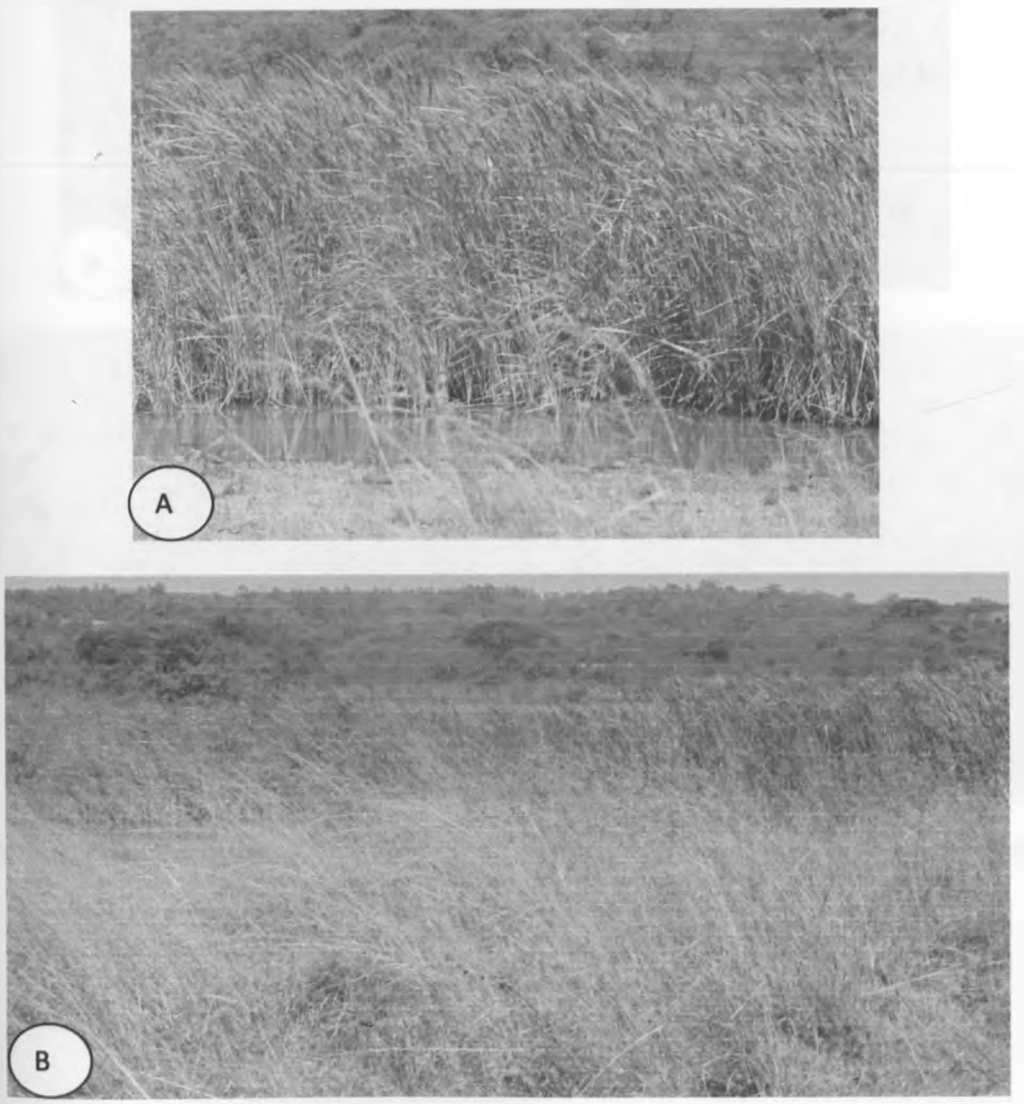

Plate 1: The vegetation (A) and general landscape (B) of Nalogomon Dam study site.

Plate 2: The vegetation (A) and general landscape (B) of Hyena Dam study site.

2.2.1 Analysis of selected physico-chemical properties of soil/ sediment

a) pH

Fifty (50) ml of deionised water was added to 20 g of air dried soil sample sieved under 2 mm sieve. It was mixed for 10 minutes using an electrical shaker and allowed to stand for 30 minutes, and stirred again for two minutes. A pH meter with a dual-calomel electrode was standardized with two buffers at pH 4 and 7 and used to determine the pH of the supernatant at 20 °C (Okalebo *et al.*, 2002).

b) Electrical Conductivity

A sample of 0.746 g KCl AR (previously dried at 105 °C for 2 hours and made to 1 litre volume with CO_2 free deionised water) was dissolved for calibration. A 1:5 soil:water suspension of 10 g air-dry soil (<2 mm) into a bottle was prepared. Fifty (50) millilitres of deionised water was added and mechanically shaken at 15 rpm for 1 hour to dissolve soluble salts. Then conductivity meter was calibrated using a KCl reference solution to obtain the cell constant. The cell was then rinsed thoroughly and the electrical conductivity of the 0.01M KCl measured at the same temperature as the soil suspensions. Repeat measurements were carried out by rinsing the conductivity cell with the soil suspension. The conductivity cell was refilled each time without disturbing the settled soil. The value indicated on the conductivity meter was then recorded. The cell was rinsed with deionised water between samples.

c) Phosphorus

The Olsen method was used to determine the extractable soil/sediment

phosphorus (Okalebo *et al.*, 2002). A 2.5 g sample of air-dried (2mm) soil/sediment was weighed into a 250 ml plastic bottle. Fifty (50) millilitres of the Olsen's extracting solution (0.5 M Na HCO_3 at pH 8.5) was added to each bottle. The contents were mixed on a mechanical shaker for 30 minutes and the suspension filtered through Whatman® No. 42 filter paper. The filtrate was used for colorimetric P measurement. The concentration of phosphorus (ppm) in the solution was obtained from the standard calibration curve, making corrections for reagent blank P concentrations. The concentration of phosphorus in the sample was calculated as follows (Equation 1):

$$\text{Olsen P, mg/kg} = \frac{c \, x \, v}{w} \quad \text{---------- Equation 1}$$

Where, c = concentration of P in the sample

V = volume of extractant

w = weight of soil/sediment

d) Nitrogen

An oven dried (105 °C) ground (<0.25 mm, 60 mesh) soil/sediment sample weighing 0.3 g was placed into a labelled, dry and clean digestion tube. A 2.5 millilitre digestion mixture (3.2 g salicylic acid in 100 ml of sulphuric acid-selenium mixture) was added to each tube and the reagent blanks for each batch of samples. Digestion was done at 110 °C for 1 hour. The temperature was then raised to 330 °C and heating continued until the solution was colourless. The

tubes were allowed to cool and the contents diluted to 100 ml with distilled water and allowed to settle so that a clear solution was taken from the top of the tube for analysis. The colorimetric method was used to determine total nitrogen (Okalebo *et al.*, 2002). The nitrogen concentration in the sample material expressed as % N was calculated as follows (Equation 2):

$$\text{Total (\%) N} = \frac{c \, x \, 0.01}{W} \text{ ----------Equation 2}$$

Where, c = concentration of N in the sample

w = weight of soil/sediment, g

*e) **Exchangeable sodium and potassium***

Exchangeable sodium and potassium was determined as described by Okalebo *et al.* (2002). Five (5) g of air dry soil/sediment (<2 mm) was weighed into a clean plastic bottle with a stopper. One hundred (100) millilitres of 1 M ammonium acetate (NH_4OAc) solution at pH 7 was added. The contents were shaken for 30 minutes and filtered through No. 42 Whatman® filter paper. Five (5) ml of the soil/sediment extract solution was pipetted into a 50 ml volumetric flask. One (1) millilitre of 26.8% lanthanum chloride solution was added and the contents diluted to the 50 ml mark with 1 M NH_4OAc extraction solution. The concentration of Na and K in the standards, sample and blank solutions was determined using a flame photometer (Jenway® Ltd, PFP 7 UK). The emission readings of the blank and standards was used to construct a standard

curve to determine the concentration of Na and K in the soil/sediment sample and calculated as follows (Equation 3):

$$\text{Na, K (mg/kg)} = \frac{(c \times v \times f)}{w} \quad \text{---------- Equation 3}$$

Where, c = concentration of Na and K in the sample extract.

v = volume of the extract solution

w = weight of the soil/sediment sample (5 g)

f = dilution factor

f) Iron

To determine the concentration of iron in the dried soil/sediment sample, selenium-sulphuric acid solution was prepared by dissolving 3.5 g selenium powder in 100 ml concentrated sulphuric acid in a beaker (Okalebo *et al.*, 2002). The solution was heated at 300 °C while covering the beaker with a watch glass and allowed to react at room temperature for 2 hours. The digestion mixture was prepared by dissolving 7.2 g salicylic acid in 100 ml of the selenium-sulphuric acid mixture. The concentration of iron in the dried sample was calculated as follows (Equation 4):

$$\text{Fe (mg/kg)} = \frac{(c \times v \times f)}{w} \quad \text{---------- Equation 4}$$

Where, c = concentration of Fe in the sample solution

v = final volume of the digest process

w = weight of the sample

f= the dilution factor

g) Sulphate

The SO_4-S in the solution was determined by the turbidity method (APHA, 1998). Precisely 5 g of air dried soil/sediment samples were weighed into a centrifuge tube. Twenty five (25) millilitres of potassium orthophosphate extracting solution (0.5491 g of KH_2PO_4 in 1 litre of distilled water) was added. The suspension was filtered through a Whatman® filter paper No. 42. The amount of sulphur in the dried sample was calculated as follows (Equation 5):

$$S\ (mg/kg) = \frac{(c\ x\ v\ x\ f)}{w} \quad \text{----------Equation 5}$$

Where, c = concentration of S in the solution

v = final volume of the sample digest

w = weight of sample taken

f = dilution factor

2.2.2 Analysis of physico-chemical parameters of water

Water chemical parameters were determined at intervals of two weeks for four months. Water samples were drawn from the four random points in triplicate

using labelled plastic bottles. The water bottles were stored in cool boxes filled with ice during transportation from the field to the laboratory. In the laboratory they were kept in a refrigerator at 4 °C awaiting analysis (APHA, 1998). One hundred (100) millilitres of the water sample were filtered through the Whatman® No. 42 filter paper for chemical analysis. Three readings were recorded at each sampling point per parameter.

a) pH

Water samples were collected at four random points in each study site using labelled plastic bottles. The samples were taken to Kenya Agricultural Research Institute in Muguga for pH determination using the method described in section 2.2.1 above. This was done before determining the chemical parameters of water.

b) Electrical conductivity

Water samples were collected at four random points in each study site using labelled plastic bottles. The samples were taken to Kenya Agricultural Research Institute in Muguga for electrical conductivity determination using the method described in section 2.2.1 above. This was done before determining the chemical parameters of water.

c) Phosphorus, nitrogen, sulphates and iron

The Olsen method was used to determine the dissolved phosphorus in the water samples. Ten (10) millilitres of the filtrate were used to determine the

concentration of P in the water samples following the procedure for soil/sediment above. The phosphate standard solutions were prepared as done for the soil/sediment in the same section (see section 2.3). Total nitrogen was determined using 0.1 ml of the filtered sample following the procedure for soil/sediment above (see section 2.2.1). The dissolved sulphates (SO_4^{2-}) were determined using 10 ml of the filtrate following the procedure for soil/sediment above (see section 2.2.1). Five (5) ml of the filtrate were used to determine the available iron following the procedure for soil/sediment above (see section 2.2.1).

d) Sodium and potassium

The dissolved sodium and potassium were determined using the procedure for soil/sediment above. The standard solutions were prepared as for the soil/sediment samples and used to obtain a standard curve. A relationship between emission and concentrations was obtained. The concentration of Na and K was calculated using the relationship (Equation 6):

Na or K (Conc.mg/L) = c x f ----------Equation 6

Where, c = concentration of Na and K in the sample

f = dilution factor

2.2.3 Analysis of plant materials for mineral elements

Plant samples collected in the field (see Section 2.1) were thoroughly washed with water and later rinsed with distilled water to remove all traces of soil from the roots, stems and other aerial plant parts. These were then cut into small portions and dried at room temperature and were ground and sifted in a sieve (0.75 mm) for chemical analysis. Chemical analysis methods used followed those by Nathan and Sun (2006). Much of their methods are based on those of Association of Official Agricultural Chemists International (AOAC).

2.2.4 Assessment of Species Diversity and Composition

Plant species diversity within the wetlands was determined by laying belt transects across each wetland. Sampling was done in 1 x 1 m quadrats placed after 5 to 10 m depending on the width of the wetland section. All the species located in the quadrats were identified and their percentage cover determined. The total count of each species in the wetlands was used to calculate the Shannon-Weiner index using the standard equation (Kent and Coker, 1992; Ludwig and Reynold, 1988) (Equation 7):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \quad \text{----------Equation 7}$$

Where, H'= index of species diversity

S= species richness (total number of species present)

Pi = proportion of total sample belonging to the i^{th} species

ln= natural log

2.2.5 Environmental gradients in the wetland soil/sediment and water

Principal Components Analysis (PCA) and Canonical Correlation Analysis (CCA) (Stevens, 1986; Kent and Coker, 1992; and Rencher, 2002) were used to identify important environmental gradients in the wetlands at Hyena and Nalogomon study sites. PC-ORD version 5 computer programme (McCune and Mefford, 1997) was used to analyse the ordination data.

2.2.6 Plant Species Identification

Plant species were identified using taxonomic keys in Agnew and Agnew (1994), Beentje (1994), Ibrahim and Kabuye (1987) and Haines and Lye (1983).

2.2.7 Data Analysis

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS 17.1). Normality of data distribution was checked by means of the skewness and kurtosis (Zar, 2001). In cases where data were found not to follow normal distribution, log transformation was used to normalize all the biological data. Differences in the physico-chemical parameters (pH, electrical conductivity and nutrients) among sites were analyzed using one-way ANOVA. Tukey's test was used to separate the means if the F value was significant. Plant species abundance and rank frequency were determined using PC-ORD version 5 (McCune and Mefford, 1997). All statistical analyses were done at probability level of $p \leq 0.5$.

CHAPTER 3: RESULTS AND DISCUSSION

3.0 Physico-chemical properties of soil/sediment

Results indicate that mineral levels in soil/sediment found in the two study sites were significantly ($p < 0.05$) different for phosphorus ($F=11.15$, $df=1$, $p < 0.05$), magnesium ($F=9.35$, $df=1$, $p < 0.05$), copper ($F=12.45$, $df=1$, $p < 0.05$) and sulphates ($F=6.18$, $df=1$, $p < 0.05$) (Appendix 1). Hyena dam study site soil/sediments had the highest accumulation of heavy metals (copper, zinc and manganese) compared to Nalogomon Dam study site (Table 3.1). Figure 4 shows that pH was not significantly ($p > 0.05$) difference between the two study sites though it was slightly higher at Hyena Dam study site.

Table 3.1: Summary of physico-chemical properties in soil/sediment at the two study sites (Means ± SE).

Variable	Nalogomon Dam	Hyena Dam
pH	6.06 ± 0.19	6.48 ± 0.14
EC (µs/cm)	360.34 ± 32.42	455.00 ± 9.53
N (%)	0.16 ± 0.02	0.22 ± 0.02
P (mg/kg)	16.65 ± 2.88	64.99 ± 14.18
K (mg/kg)	557.17 ± 62.44	380.86 ± 60.67
Ca (mg/kg)	4450.25 ± 229.56	4007.00 ± 332.84
Mg (mg/kg)	741.76 ± 53.88	505.39 ± 55.39
Na (mg/kg)	681.02 ± 53.00	970.94 ± 122.31
Cu (mg/kg)	2.75 ± 0.26	4.73 ± 0.50
Zn (mg/kg)	15.19 ± 2.77	17.60 ± 3.92
Mn (mg/kg)	2419.92 ± 267.71	3084.04 ± 248.95
Fe (mg/kg)	2296.40 ± 700.36	2195.24 ± 449.94
SO_4 (mg/kg)	92.09 ± 16.01	145.56 ± 14.35

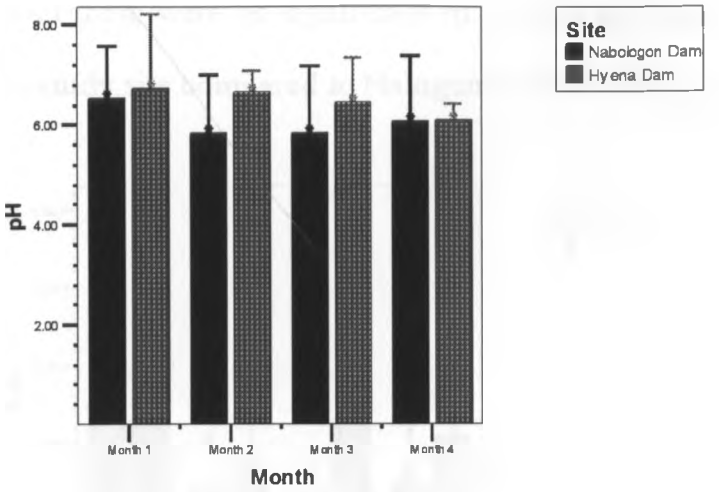

Fig. 4: Levels of soil/sediment pH at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Electrical conductivities of soil/sediment decreased during the wet season at both study sites; they were slightly higher but not significantly ($F=2.55$, $df=1$, $p > 0.05$) for Hyena Dam study site compared to Nalogomon Dam study site (Figure 5).

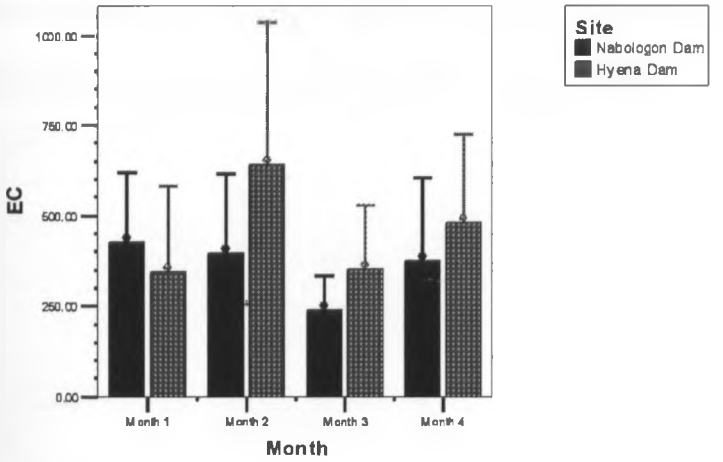

Fig. 5: Levels of soil/sediment EC at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Results showed that there were no significant ($p > 0.05$) differences in levels of N for Hyena Dam study site compared to Nalogomon Dam study site (Fig. 6).

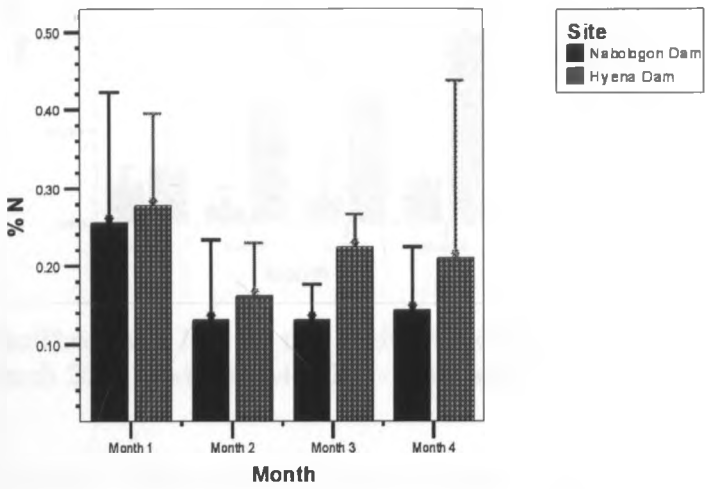

Fig. 6: Levels of soil/sediment N at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

There were significant ($p < 0.05$) differences in levels of P between Nalogomon and Hyena study sites (Fig. 7). Levels of P in Hyena Dam increased significantly ($p < 0.05$) during the rainy season as compared to the dry season while those for Nalogomon Dam did not show any significant ($P > 0.5$) change.

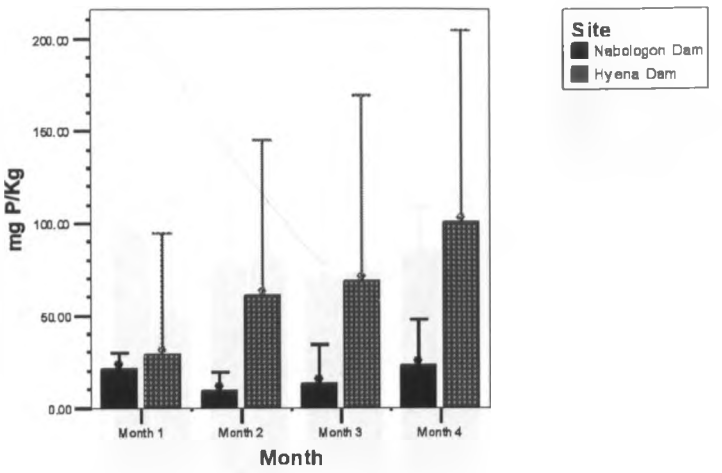

Fig. 7: Levels of soil/sediment P at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Significant ($p < 0.05$) differences in mean levels of K were observed between Nalogomon and Hyena study sites (Fig. 8) with those of Nalogomon Dam staying at higher levels than those of Hyena Dam.

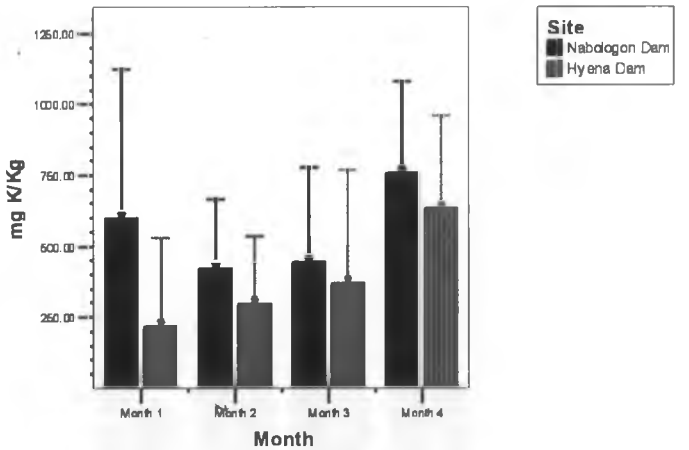

Fig. 8: Levels of soil/sediment K at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

There were no significant ($p > 0.05$) differences in mean levels of Ca between Nalogomon and Hyena study sites (Fig. 9).

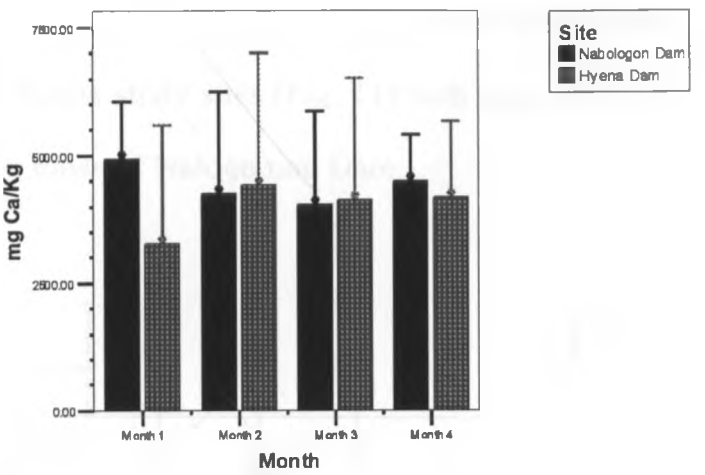

Fig. 9: Levels of soil/sediment Ca at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were significant ($p < 0.05$) differences in mean levels of Mg between Nalogomon and Hyena study sites (Fig. 10) with those of Nalogomon Dam higher than those of Hyena Dam. Hyena Dam Mg levels did not show much change between seasons.

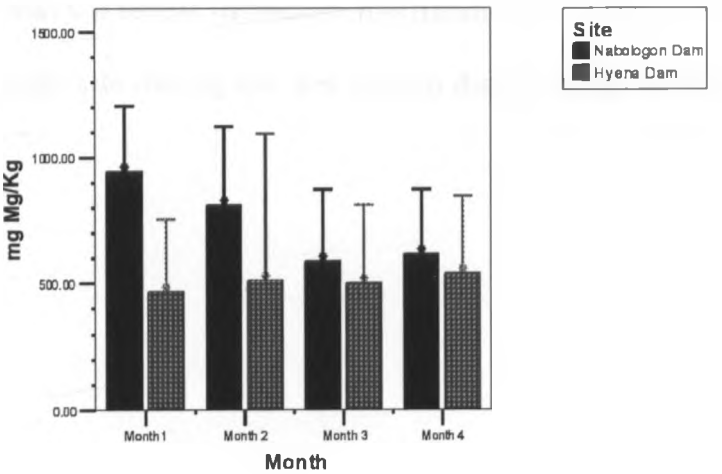

Fig. 10: Levels of soil/sediment Mg at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

There were significant ($p < 0.05$) differences in mean levels of Na between Nalogomon and Hyena study sites (Fig. 11) with those of Hyena Dam staying at higher levels than those of Nalogomon Dam.

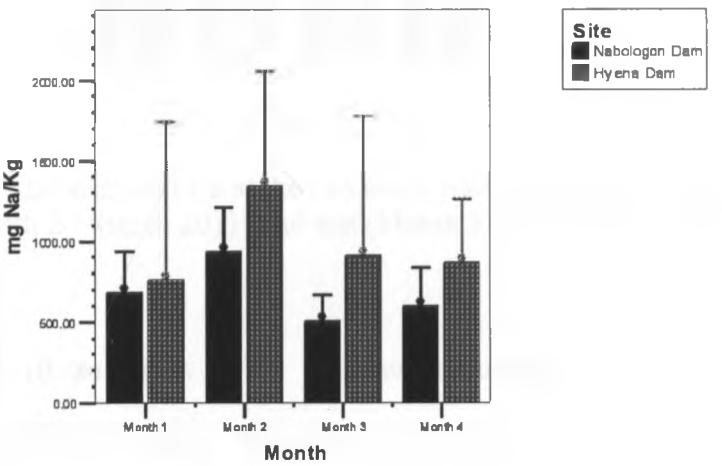

Fig. 11: Levels of soil/sediment Na at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Results showed that Cu levels increased significantly ($P < 0.05$) in soil/sediments at Hyena Dam study site during the wet season than was the case for Nalogomon Dam (Fig. 12).

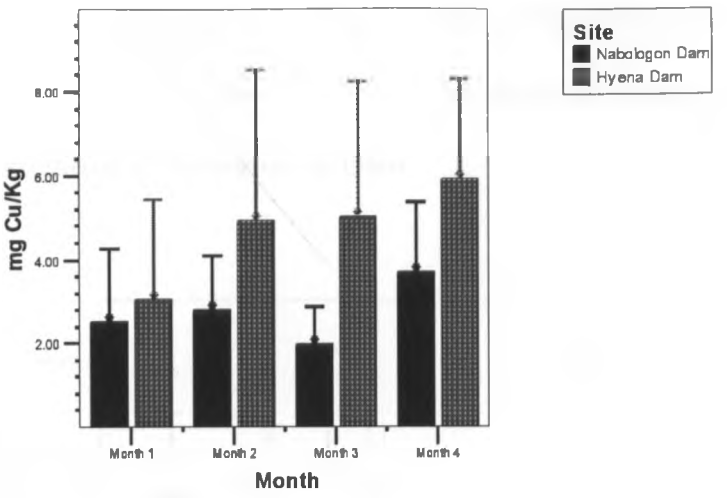

Fig. 12: Levels of soil/sediment Cu at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

There were significant ($p < 0.05$) differences in mean levels of Zn between Nalogomon and Hyena study sites (Fig. 13) during the dry season months. However, after rains there were no significant ($p > 0.05$) differences between Nalogomon Dam and Hyena Dam.

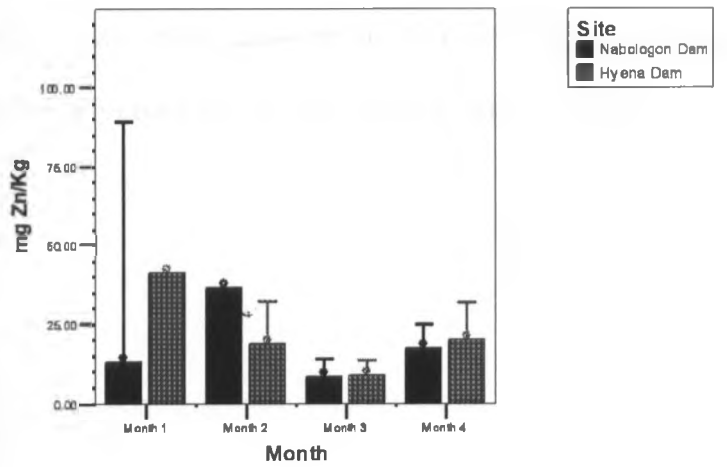

Fig. 13: Levels of soil/sediment Zn at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Significant ($p < 0.05$) differences in mean levels of Mn were observed between Nalogomon and Hyena study sites (Fig. 14) with those of Hyena Dam staying at higher levels than those of Nalogomon Dam.

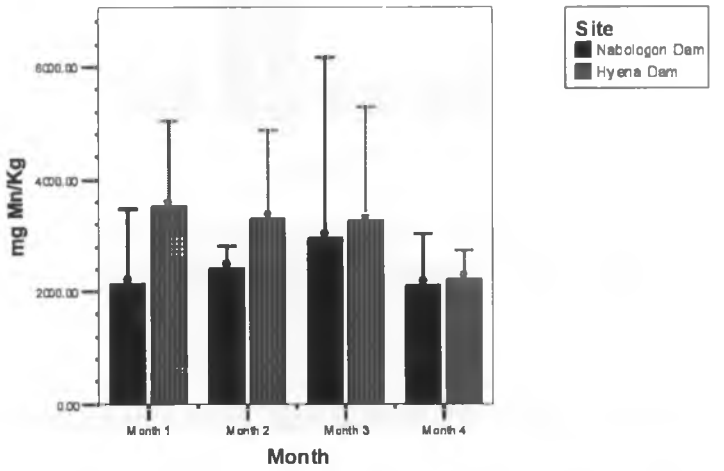

Fig. 14: Levels of soil/sediment Mn at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

There were significant ($p < 0.05$) differences in mean levels of Fe between Nalogomon and Hyena study sites (Fig. 15) with those of Nalogomon Dam higher than those of Hyena Dam during the dry season months.

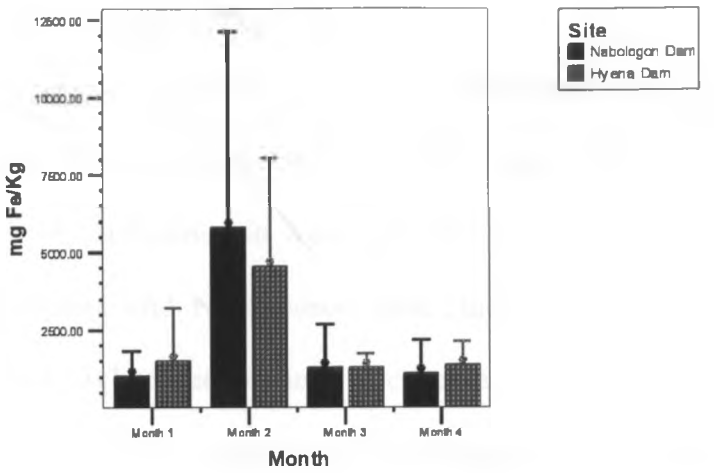

Fig. 15: Levels of soil/sediment Fe at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Sulphates in soil/sediments were significantly ($p < 0.05$) higher in the dry season decreasing during the wet season at Hyena Dam site (Fig. 16). Levels of sulphates did not vary significantly ($p < 0.05$) for Nalogomon Dam site.

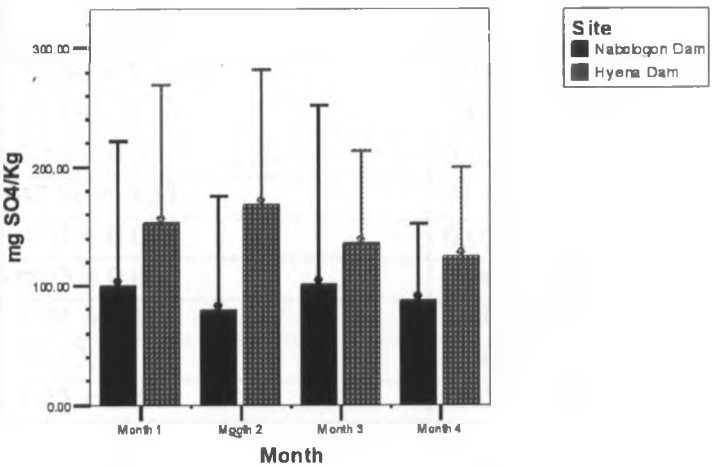

Fig. 16: Levels of soil/sediment SO_4 at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

3.1 Physico-chemical parameters of water

Generally, there were significant ($p < 0.05$) differences in manganese and sulphates between Hyena and Nalogomon study sites. There was however no significant ($p > 0.05$) difference in water pH, EC, N, P, K, Ca, Mg, Na, Cu, Zn and Fe between Hyena and Nalogomon dam study sites (Appendix 2). Hyena Dam study site had higher heavy metal accumulation copper (0.02±0.00 mg/L) and Zinc (0.06±0.02 mg/L) compared to Nalogomon Dam study site, copper (0.001±0.00 mg/L) and Zinc (0.05±0.01 mg/L) respectively (Table 3.2).

Table 3.2: Summary of physico-chemical properties in water at the two study sites (Means ± SE).

Parameter	Nalogomon Dam	Hyena Dam
pH	7.38 ± 0.09	7.13 ± 0.12
EC (µs/cm)	399.62 ± 11.72	445.31 ± 51.96
N (%)	0.03 ± 0.01	0.04 ± 0.03
P (mg/L)	0.49 ± 0.11	0.72 ± 0.16
K (mg/L)	20.46 ± 5.51	19.91 ± 5.64
Ca (mg/L)	15.19 ± 2.26	14.47 ± 1.77
Mg (mg/L)	3.58 ± 0.52	2.95 ± 0.46
Na (mg/L)	42.86 ± 6.51	51.41 ± 9.76
Cu (mg/L)	0.01 ± 0.00	0.02 ± 0.00
Zn (mg/L)	0.05 ± 0.01	0.06 ± 0.02
Mn (mg/L)	1.04 ± 0.17	3.66 ± 0.49
Fe (mg/L)	16.33 ± 2.76	19.02 ± 7.31
SO_4 (mg/L)	7.25 ± 1.34	3.43 ± 0.98

Electrical conductivity (EC) was higher during dry season in Hyena Dam study site though not significantly ($F=0.73$, $df=1$, $p > 0.05$) but decreased to near same level as Nalogomon Dam study site levels during wet season (Fig. 17).

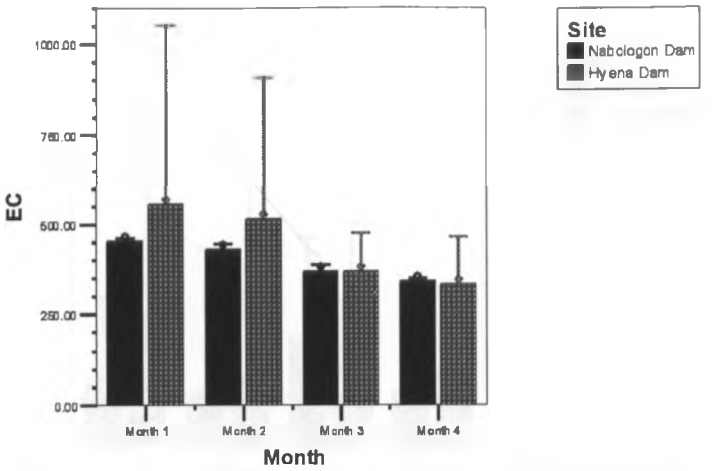

Fig. 17: Levels of water EC at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Results showed that there was no significant ($p > 0.05$) difference in water N between Hyena and Nalogomon dam study sites. However, levels of Nitrogen increased significantly ($P < 0.05$) during the first month of the rain season at both research sites (Fig. 18).

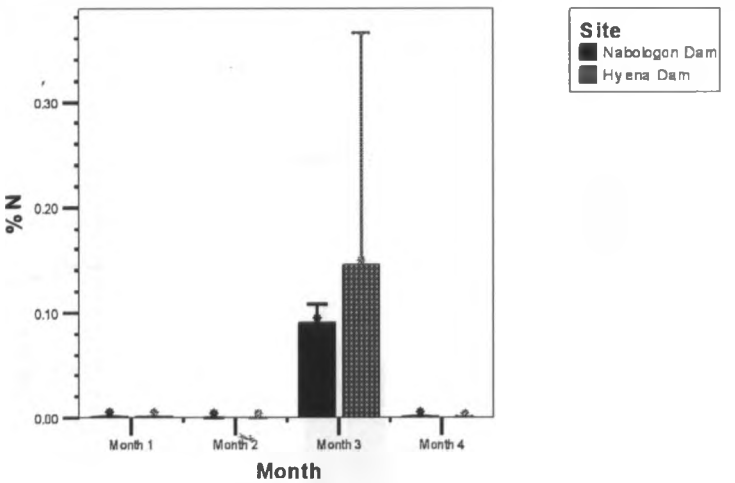

Fig. 18: Levels of water N at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons

There was however no significant ($p > 0.05$) difference in water P between Hyena and Nalogomon dam study sites (Fig. 19).

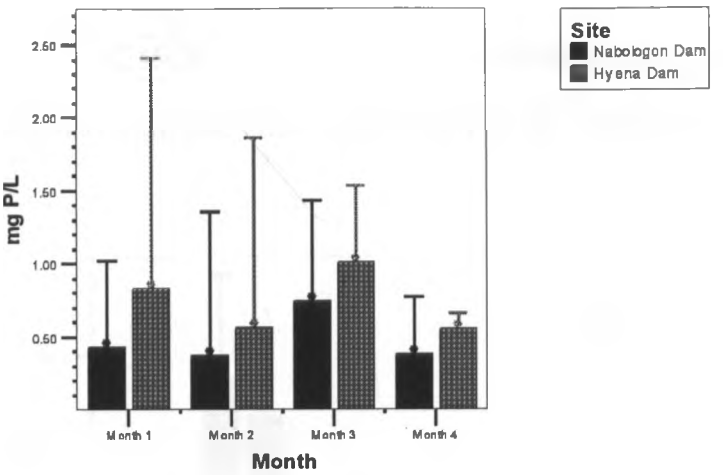

Fig. 19: Levels of water P at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

There was however no significant ($p > 0.05$) difference in water K between Hyena and Nalogomon dam study sites (Fig. 20). However they increase significantly ($p < 0.05$) during the start of the rain season at both study sites

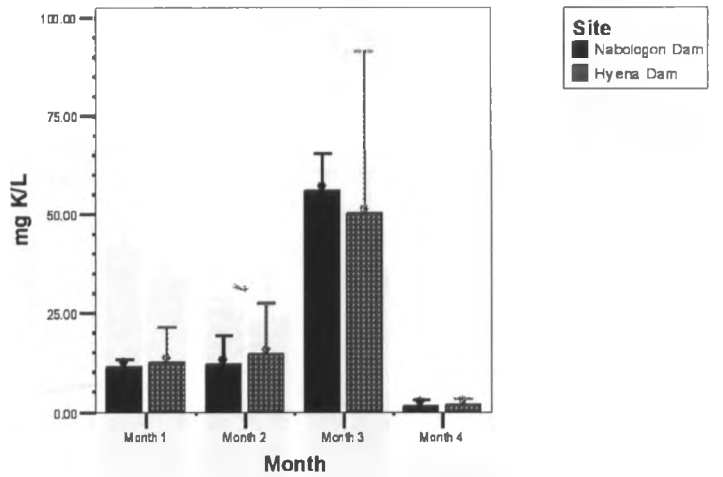

Fig. 20: Levels of water K at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Ca between Hyena and Nalogomon dam study sites (Fig. 21).

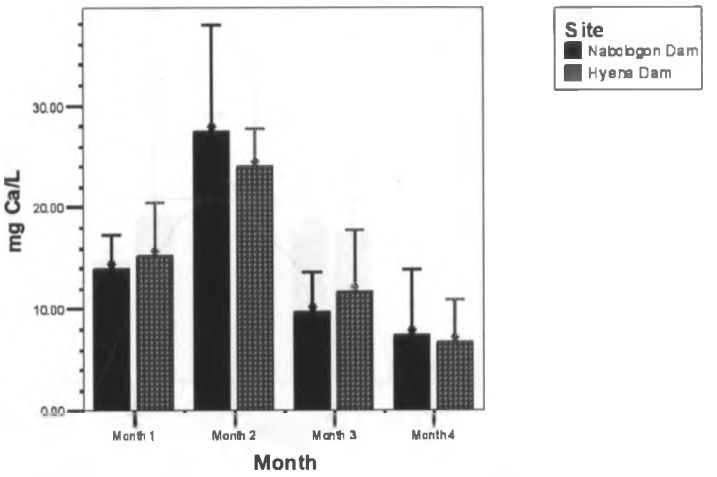

Fig. 21: Levels of water Ca at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Mg between Hyena and Nalogomon dam study sites (Fig. 22).

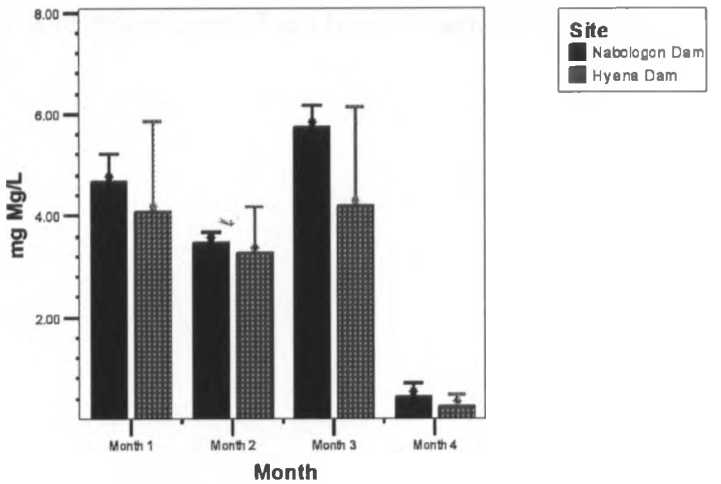

Fig. 22: Levels of water Mg at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Na between Hyena and Nalogomon dam study sites (Fig. 23).

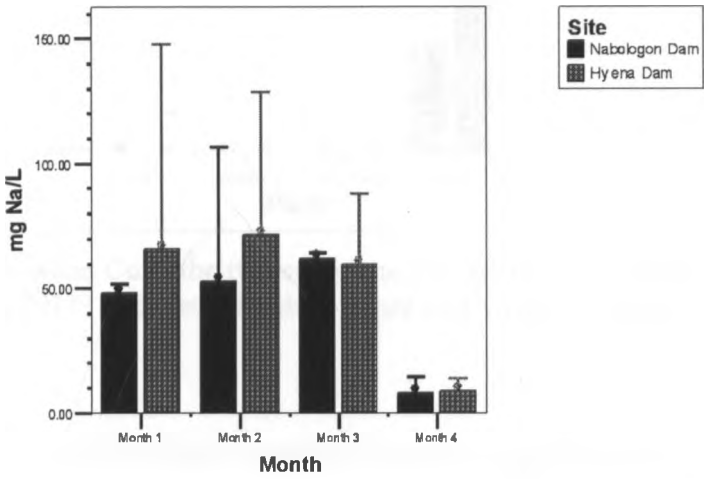

Fig. 23: Levels of water Na at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Cu between Hyena and Nalogomon dam study sites (Fig. 24). However there was a significant ($p < 0.05$) increase of Cu at both study sites in the rainy season with highest levels recorded at Hyena Dam study site.

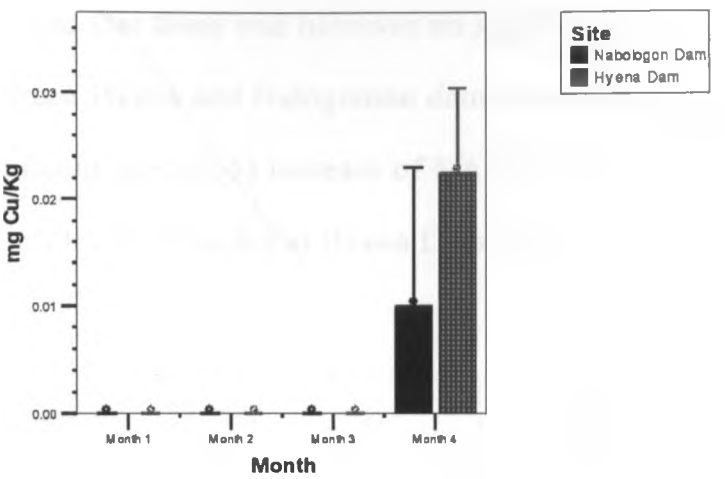

Fig. 24: Levels of water Cu at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Zn between Hyena and Nalogomon dam study sites (Fig. 25). However there was a significant ($p < 0.05$) increase of Zn at both study sites in the rainy season with highest levels recorded at Hyena Dam study site.

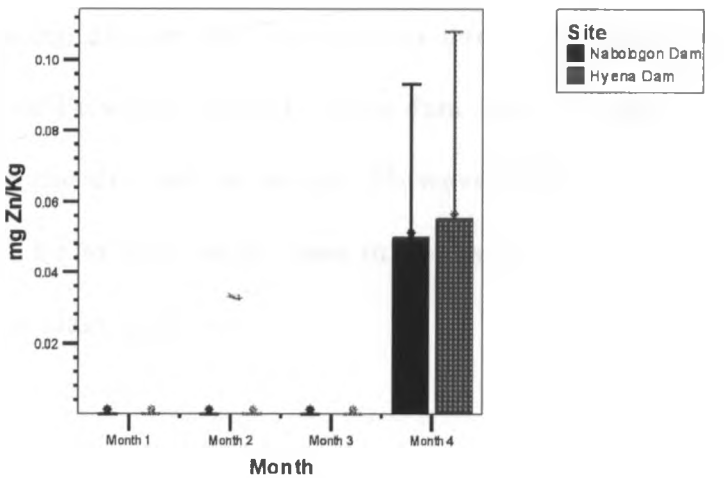

Fig. 25: Levels of water Zn at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Mn between Hyena and Nalogomon dam study sites (Fig. 26). However there was a significant ($p < 0.05$) increase of Mn at both study sites in the rainy season with highest levels recorded at Hyena Dam study site.

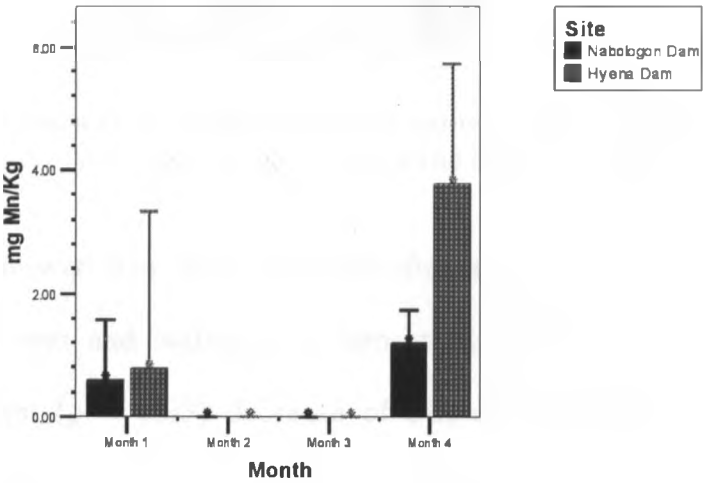

Fig. 26: Levels of water Mn at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there was however no significant ($p > 0.05$) difference in water Fe between Hyena and Nalogomon dam study sites (Fig. 27). It was noted that levels of Fe were lower at Hyena dam study site than Nalogomon dam study site during the dry season month. However there was a significant ($p < 0.05$) increase of Fe at both study sites in the rainy season with highest levels recorded at Hyena Dam study site.

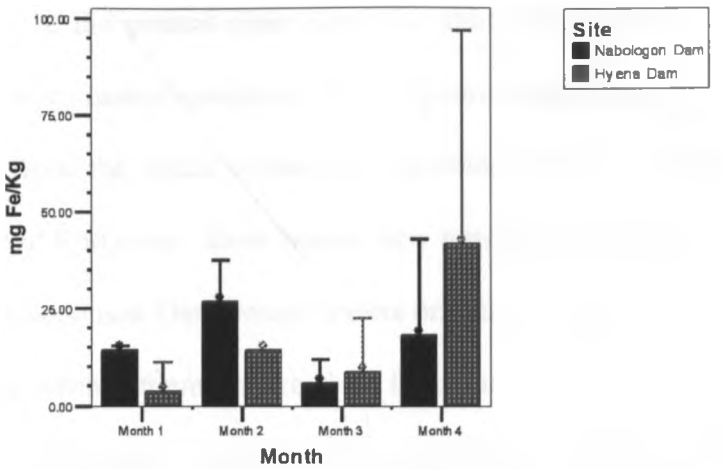

Fig. 27: Levels of water Fe at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were significant ($p < 0.05$) differences in water SO_4 between Hyena and Nalogomon dam study sites (Fig. 28). However there was a significant ($p < 0.05$) decrease of SO_4 at both study sites in the rainy season.

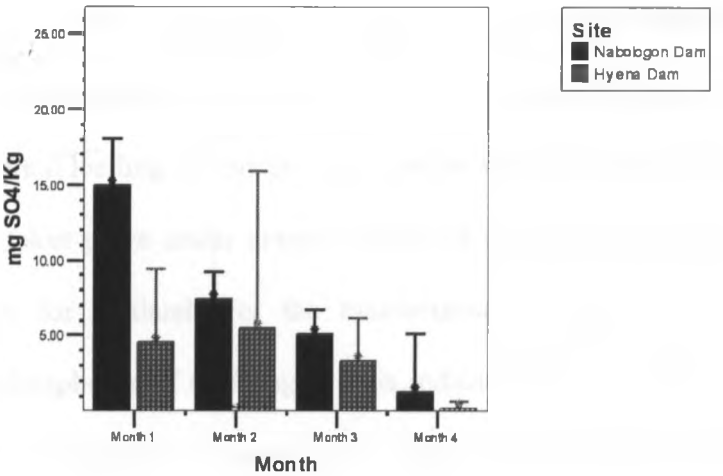

Fig. 28: Levels of water SO_4 at the two study sites during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

The results of the present study generally show that Hyena Dam study site had higher levels of heavy metals compared to Nalogomon Dam study site. As Hyena Dam waters originate from the urban estates and facilities, such as Langata Barracks and Carnivore Hotel and Restaurant, these waters carry nutrients loaded effluents into the dam as compared to Nalogomon Dam whose waters originate primarily in the a larger forest watershed and the urban settlements are more far off in comparison. It was noted during the study that grazing animals (including zebra, warthogs, buffaloes, gazelles, etc) and a variety of bird life concentrated around Hyena Dam area during the dry season. The area served as a dry season grazing area due to the presence of green forage and drinking water. The heavy presence of copper in the water could be a potential health hazard to the animals as high levels of copper have been found to cause oxidative damage to lipids, proteins and DNA leading to liver cirrhosis and kidney necrosis in animals (Gaetke and Chow, 2003).

Total phosphorus and cations levels were lowest in at Nalogomon Dam and highest at Hyena Dam both for the water and soil/sediment. It was again observed that there were higher levels of these elements for soil/sediment than for water at both study sites. There appears to be internal loading of phosphorous into the waters by release of sediment bound phosphorus that takes place under anoxic conditions (Erskine and Saynor, 1996). Water policy guidelines for wetlands for the maintenance of aquatic ecosystems stipulate maximum total phosphorus of 0.05 mg/L. This indicates therefore that total phosphorous for water of Hyena Dam (at 0.72 mg/L) has already exceeded this threshold. Hence, the water is already eutrophicated and wildlife drinking these waters, especially during the dry season when the area is a high concentration grazing area due to availability of green vegetation and water, are taking more phosphorous than would be permitted. In wetland

bodies, nutrients play a major role as their excesses lead to eutrophication. There was a high level of nitrogen at Hyena Dam than at Nalogomon Dam with levels approaching those of polluted wetland systems of 0.5 mg/L (Bilger and Atkinson, 1997). Under normal conditions the nitrate content of surface water occur in trace amount but the level is enhanced by the inputs from anthropogenic sources. Excessive macrophytic vegetation is indicative of the eutrophication status of any wetland. Hence, eutrophication is occurring in the Hyena Dam water body as exemplified by the growth of aquatic weeds.

The pH values ranged between 6.06 at Nalogomon Dam study site and 6.48 at Hyena Dam study site. On average, the values of conductivity, copper, zinc, iron and manganese were higher at Hyena Dam compared to Nalogomon Dam. The quality of water in different phases of a natural aquatic system is reflected by the level of the physico-chemical parameters. Since there is a large human settlement around the Carnivore Hotel up-slope near Hyena Dam, the higher values of all these physico-chemical parameters obtained at Hyena Dam than at Nalogomon Dam could be as a result of pollution from human activities (Vogel, 1970). The higher presence of heavy metals at Hyena Dam than Nalogomon Dam could not be attributed to geological distribution of minerals since the geological substrate for the two areas are similar. The highest concentration of zinc (0.06 mg/L) was obtained at Hyena Dam and this could be attributed to zinc based chemicals from human activities (Egila and Nimyel, 2002). In addition, high levels of iron were found in all the water samples. The highest concentration was at Hyena Dam (19.02 mg/L) compared with values at Nalogomon Dam (16.33 mg/L). This was expected because the original soil substrate of the two sites is nitisol soils known to be rich in sesquioxides of iron, aluminium and manganese.

Water calcium content at Nalogomon Dam was 15.19 mg/L and in Hyena Dam was 14.47 mg/L. In aquatic environments, calcium serves as one of the micronutrients for most of the organisms. On the basis of calcium richness, water bodies are classified into; (i) poor, (ii) medium, and (iii) rich water bodies with regard to calcium content. According to this classification both Hyena and Nalogomon study sites fall under the category of medium to rich calcium waters.

3.2 Seasonal variation in water physico-chemical properties

3.2.1 Hyena Study Site

There was a significant an increase in nitrogen, phosphorus, potassium, iron and manganese levels during the wet season. The levels of calcium, magnesium, sodium and sulphates were significantly ($p < 0.05$) high during dry season decreasing during wet season (Table 3.3)

Table 3.3: Hyena study site seasonal variations in water physico-chemical properties (Means ± SE)

Parameter	Dry season	Wet season
pH	7.11 ± 0.11	7.14 ± 0.22
EC (µs/cm)	536.37 ± 92.56	354.25 ± 25.19
N (%)	0.0012 ± 0.00	0.072 ± 0.04
P (mg/L)	0.7 ± 0.3	0.75 ± 0.10
K (mg/L)	13.64 ± 2.32	26.19 ± 10.93
Ca (mg/L)	19.70 ± 1.89	9.24 ± 1.41
Mg (mg/L)	3.68 ± 0.32	2.22 ± 0.80
Na (mg/L)	68.77 ± 14.56	34.04 ± 10.48
Mn (mg/L)	3.18 ± 0.00	3.78 ± 0.61
Cu (mg/L)	0.31 ± 0.21	0.41 ± 027
Zn (mg/L)	0.62 ± 0.42	0.89 ± 0.57
Fe (mg/L)	6.28 ± 2.94	25.39 ± 10.33
SO_4 (mg/L)	5.04 ± 1.68	1.81 ± 0.72

Analysis of variance for spatial variability on physico-chemical parameters showed that sampling points at Nalogomon Dam study site did not differ significantly from each other (Table 3.4) while at the Hyena Dam, sampling point 4, that was located closer to urban settlements, differed significantly from the other three sampling points (Table 3.5). This was especially so for heavy metals (namely Cu and Mn), EC, Na and phosphorous. These elements were higher at sampling point 4 than the other three sampling points (Figs. 32, 34, 37 and 38 respectively)

Table 3.4: ANOVA on water physico-chemical properties between the four sampling points at Hyena dam

Variable	Sum of Squares	df	Mean Square	F	Level of Significance
pH	0.28	3	0.09	0.35	0.79
EC	365319.69	3	121773.23	5.17	0.02
N	0.02	3	0.01	0.54	0.67
P	0.92	3	0.31	0.72	0.50
K	1199.81	3	399.94	0.75	0.54
Ca	31.03	3	10.34	0.17	0.91
Mg	1.78	3	0.59	0.15	0.93
Na	8548.74	3	2849.58	2.39	0.12
Cu	6.04	3	2.01	42.45	0.00
Zn	26.70	3	8.90	53.12	0.00
Mn	4.51	3	1.50	5.80	0.29
Fe	796.85	3	265.62	0.34	0.80
SO4	54.62	3	18.21	1.25	0.33

Table 3.5: ANOVA on water physico-chemical properties between the four sampling points at Nalogomon Dam

Variable	Sum of Squares	df	Mean Square	F	Level of Significance
pH	0.05	3	0.02	0.11	0.96
EC	242.25	3	80.75	0.03	0.99
N	0.00	3	0.00	0.02	1.00
P	0.41	3	0.14	0.70	0.50
K	18.76	3	6.25	0.01	1.00
Ca	58.20	3	19.40	0.21	0.89
Mg	0.18	3	0.06	0.01	1.00
Na	883.90	3	294.63	0.38	0.77
Cu	0.00	3	0.00	2.74	0.09
Zn	0.00	3	0.00	0.77	0.53
Mn	0.70	3	0.23	1.55	0.36
Fe	202.74	3	67.58	0.50	0.69
SO_4	0.56	3	0.19	0.01	1.00

Study results showed that there were no significant ($p > 0.05$) differences in water EC between dry and wet season at Hyena Dam study site (Fig. 29). However the levels highest at sampling site Number 4 near human settlements.

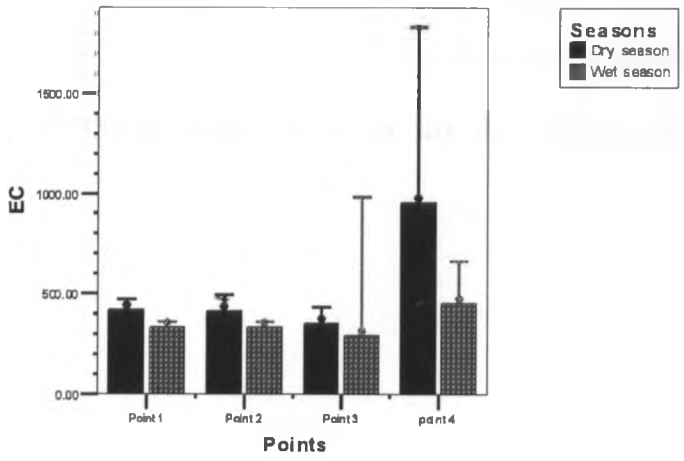

Fig. 29: Levels of water EC at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were no significant ($p > 0.05$) differences in water K between sampling points Numbers 1 to 3 (Fig. 30). However there was a significant ($p < 0.05$) increase of K in the wet season at sampling point Number 4.

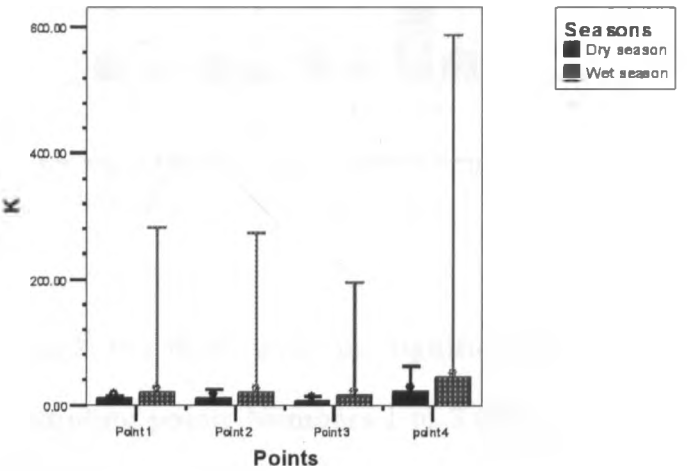

Fig. 30: Levels of water K at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were no significant ($p > 0.05$) differences in water Na between sampling points Numbers 1 to 3 (Fig. 31). However there was a significant ($p < 0.05$) increase of Na in the dry season at sampling point Number 4.

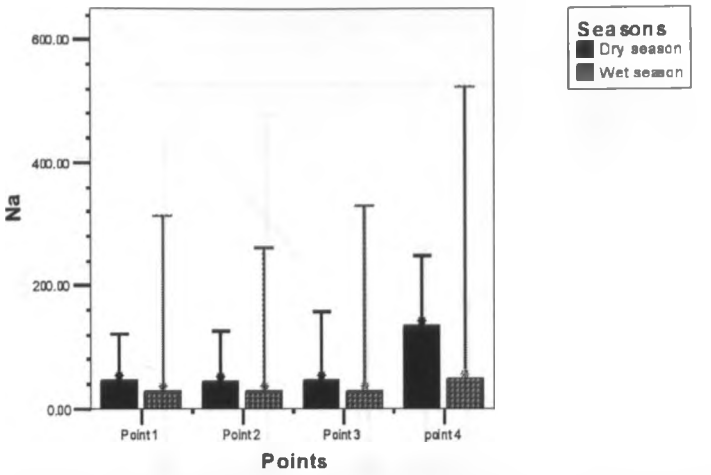

Fig. 31: Levels of water Na at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were no significant ($p > 0.05$) differences in water P between sampling points Numbers 1 to 3 (Fig. 32). However there was a significant ($p < 0.05$) increase of P in the dry season at sampling point Number 4.

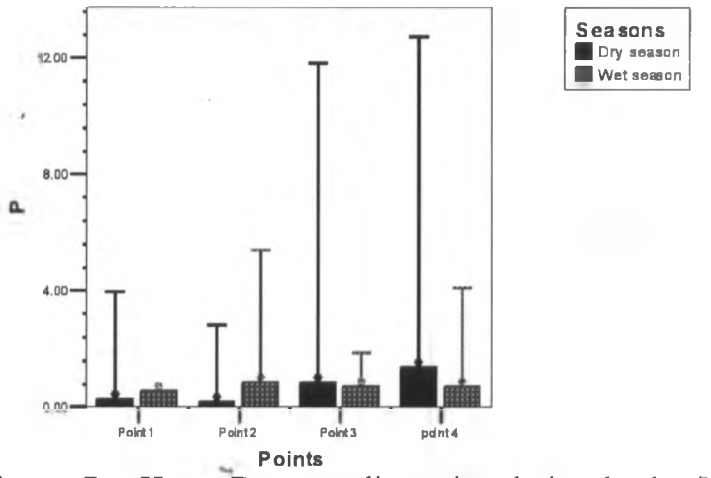

Fig. 32: Levels of water P at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were no significant ($p > 0.05$) differences in water Mn between sampling points Numbers 1 to 3 (Fig. 33)

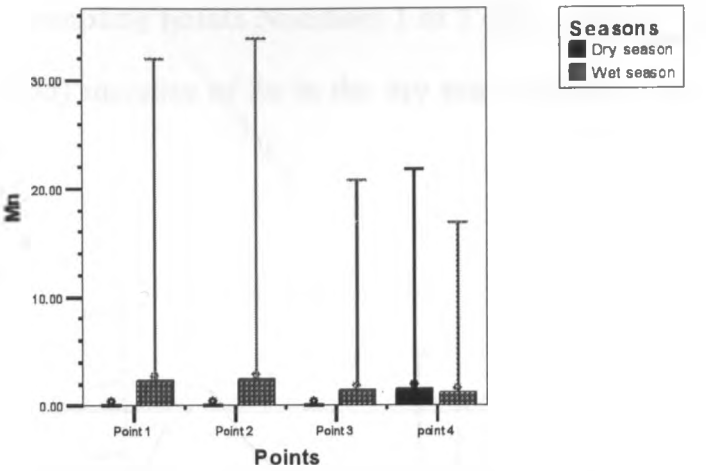

Fig. 33: Levels of water Mn at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 – April and Month 4 - May 2011) seasons.

Study results showed that there were no significant ($p > 0.05$) differences in water Cu between sampling points Numbers 1 to 3 (Fig. 34). However there was a significant ($p < 0.05$) increase of Cu in the dry season at sampling point Number 4.

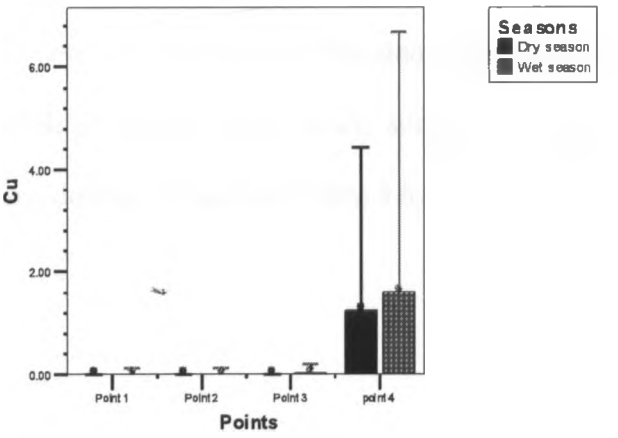

Fig. 34: Levels of water Cu at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

Study results showed that there were no significant ($p > 0.05$) differences in water Zn between sampling points Numbers 1 to 3 (Fig. 35). However there was a significant ($p < 0.05$) increase of Zn in the dry season at sampling point Number 4.

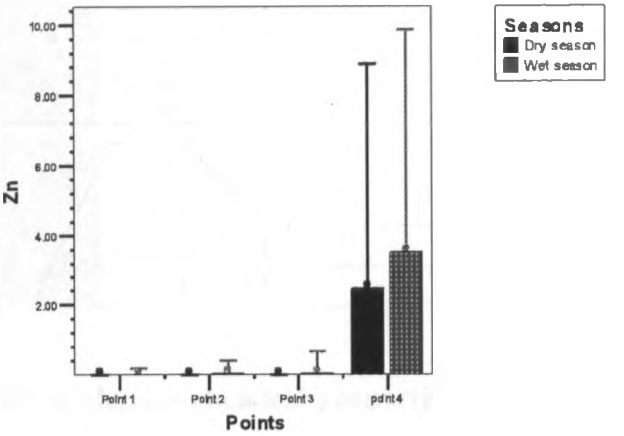

Fig. 35: Levels of water Zn at Hyena Dam sampling points during the dry (Month 1 - February and Month 2 - March 2011) and wet (Month 3 - April and Month 4 - May 2011) seasons.

3.2.2 Nalogomon study site seasonal variation

There was an increase in levels of phosphorus, Nitrogen, potassium and manganese during wet season, while the levels of calcium, magnesium, sodium, iron and sulphates were high during dry season and low during wet season (Table 3.6)

Table 3.6: Nalogomon Dam seasonal variations in water physico-chemical properties (Means ± SE)

Parameter	Dry season	Wet season
pH	7.48 ± 0.10	7.27 ± 0.15
EC (µs/cm)	442.62 ± 5.25	356.62 ± 5.73
N (%)	0.01 ± 0.001	0.04 ± 0.02
P (mg/L)	0.39 ± 0.16	0.58 ± 0.14
K (mg/L)	12.07 ± 1.06	28.86 ± 10.43
Ca (mg/L)	20.75 ± 3.01	8.82 ± 0.97
Mg (mg/L)	4.07 ± 0.24	3.09 ± 1.01
Na (mg/L)	50.49 ± 7.87	35.24 ± 10.15
Cu (mg/L)	0.33 ± 0.003	0.038 ± 0.004
Zn (mg/L)	0.030 ± 0.003	0.028 ± 0.002
Mn (mg/L)	0.81 ± 0.30	1.21 ± 0.16
Fe (mg/L)	20.65 ± 2.81	11.99 ± 4.39
SO_4 (mg/L)	11.20 ± 1.51	3.23 ± 0.93

3.3 Seasonal variability in physico-chemical properties

The slight decrease in pH during the dry season was mainly due to low fresh water discharge and increased evaporation, while the decrease water salinity during the wet season was due to, dilution by heavy rainfall and increase in fresh water discharge. The findings of this study agree closely with results of studies carried out on salinity of wetland surface water in other water bodies (Ajao, 1990). The influx of water mainly due to rainfall is a major factor controlling the seasonal distribution of nutrients in wetlands.

The observed increase in phosphorous levels at the two study sites during the wet season as compared to the dry season can be attributed to increases in suspended sediment in the waters transported by run-off (Ajao 1990). It could also be attributed to internal loading of phosphorous into the waters by the release of sediment bound phosphorus under anoxic conditions (Erskine and Saynor, 1996). The higher levels of nutrients such as

sulphates, nitrogen and phosphates at both study sites during the dry season could also be due to evaporation.

In the present study, magnesium content was higher (3.58 mg/L) at Nalogomon Dam and lower (2.95 mg/L) at Hyena Dam (Tables 3.8 and 3.9). Levels were higher during the wet season and low during the dry season. Magnesium is often associated with calcium in all kinds of waters, but its concentration remains generally lower than that of calcium.

Potassium is also a naturally occurring element like sodium, but its concentration in fresh water bodies remains lower than of sodium. It is probable that sedimentation and utilization of potassium by biota without any extra influx through runoff during the dry season caused decrease in its content at both study sites (Garg *et al.*, 2006). Under low potassium concentration, algal growth rate and photosynthesis are poor while respiration is increased.

The observed seasonal changes in heavy metals (copper and zinc) during the rainy seasons are attributed to increased effect of surface run-off, soil erosion from the loosened soils by animal trampling during the dry season, and urban effluents discharges into the receiving water bodies.

3.4 Plant tissue chemical analysis

There was significant ($F=7.646$, $df=1$, $p < 0.05$) difference in plant tissue nitrogen and phosphorus ($F=5.672$, $df=1$, $p < 0.05$) for plant species found in Hyena and Nalogomon Dam study sites (Appendix 3). However, levels of K, Ca, Mg, Na, Fe and manganese were not significantly ($p > 0.05$) different for plant tissues at Hyena and Nalogomon study sites (Appendix 3). It was noted that plant

tissues at Hyena Dam had higher mean levels of iron (0.63±0.12 mg/kg) and potassium (1.82±0.27 mg/kg) compared with Nalogomon Dam with (0.47±0.09 mg/kg) and (1.56±0.23 mg/kg) for iron and potassium respectively (Table 3.7). Plant tissues from Hyena Dam study site had higher levels of nitrogen compared to those of plants from Nalogomon Dam study site (Figure 36). This could be attributed to higher nutrient loading into the Hyena Dam study site waters that originate from nearby human settlements that were selectively taken up by plants.

Table 3.7: Chemical properties of plant tissues at the two study sites (Means ± SE)

Parameter	Nalogomon Dam	Hyena Dam
N (%)	2.14 ± 0.16	3.49 ± 0.39
P (mg/kg)	0.19 ± 0.01	0.34 ± 0.05
K (mg/kg)	1.56 ± 0.23	1.82 ± 0.27
Ca (mg/kg)	0.59 ± 0.05	0.74 ± 0.09
Mg (mg/kg)	0.16 ± 0.02	0.14 ± 0.01
Na (mg/kg)	0.64 ± 0.13	0.66 ± 0.11
Fe (mg/kg)	0.47 ± 0.09	0.63 ± 0.12
Mn (mg/kg)	0.31 ± 0.09	0.35 ± 0.06

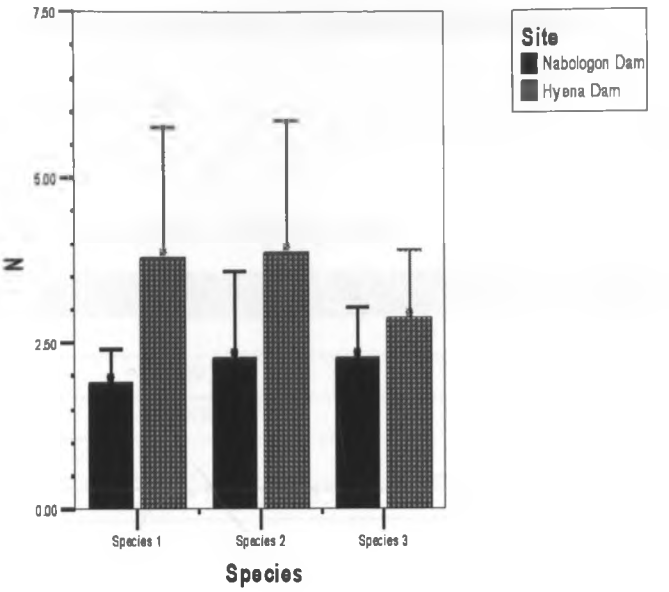

Figure 36: Plant tissue Nitrogen at the two study sites (Species 1- Typha, Species 2- Sedges and species 3 - Grasses)

3.5 Plant species diversity and composition

The two study sites had a diverse plant species composition based on total number of species and the Shannon H' plant species diversity index (Table 3.8). A total of 32 plant species were identified in Hyena and 28 in Nalogomon study sites Tables 3.9 and 3.10). The number of rare plant species was highest at Hyena Dam and lowest at Nalogomon Dam. Therefore, the Hyena Dam study site was the most diverse in plant species compared to Nalogomon Dam study site (Hyena Dam > Nalogomon Dam). Likewise, the common plant species numbers were highest at Hyena Dam and lowest at Nalogomon Dam (Figure 37). The five most frequent and dominant plant species at Hyena Dam were *Cynodon dactylon*, *Digitaria scalarum*, *Themeda triandra*, *Cyperus dives,* and *Heteropogon contortus* (Table 3.9), while at Nalogomon Dam the five most frequent species were

Hyparrhemia rufa, Typha domingensis, Ischaemum branchyatherum, Themeda triandra and *Acacia gerandii* (Table 3.10).

Table 3.8: Shannon H' plant species diversity index

Value	Nalogomon Dam	Hyena Dam
Species number	28	32
Shannon H'	2.095	2.259
Variance	0.00039205	0.00039519
t: = -15.844		
df = 3841.2	P = 8.0968E-55	

Table 3.9: Species list summary showing rank abundance and families of plants found in Hyena dam in Nairobi National park.

Hyena Dam Species Name	Family	Rank Abundance	Log (Sum Abundance
Cynodon dactylon	*Poaceae*	1	3.08
Digitaria scalarum	*Poaceae*	2	3.07
Themeda triandra	*Poaceae*	3	3.07
Cyperus dives	*Cyperaceae*	4	2.78
Heteropogon contortus	*Poaceae*	5	2.74
Typha domingensis	*Typhaceae*	6	2.56
Hyparrhenia rufa	*Poaceae*	7	2.46
Aspilia mossambicensis	*Asteraceae*	8	2.42
Chloris roxburghiana	*Poaceae*	9	2.39
Eragrostis sp	*Poaceae*	10	2.37
Orthosiphon sp	*Lamiaceae*	11	2.32
Gunnera perpensa	*Gunneraceae*	12	2.29
Ludwigia abyssinica	*Onagraceae*	13	2.12
Pennisetum mezianum	*Poaceae*	14	2.08
Ocimum kenyensis	*Lamiaceae*	15	2.07
Rhynchosia minima	*Leguminosae*	16	2.07
Indigofera arrecta	*Leguminosae*	17	2.06
Asystasia laticapsula	*Acanthaceae*	18	2.05
Achyranthes aspera	*Amaranthaceae*	19	2.03
Setaria sphacelata	*Poaceae*	20	2
Enhydra fluctuans	*Amaranthaceae*	21	1.94
Becium obovatum	*Labiatae*	22	1.92
Solanum incanum	*Solanaceae*	23	1.92
Nesaea kilimandscharica	*Euphorbiaceae*	24	1.91
Dychoriste radicans	*Acanthaceae*	25	1.91
Lantana camara	*Verbenaceae*	26	1.9
Sida tenuicarpa	*Malvaceae*	27	1.87
Commelina benghalensis	*Commelinaceae*	28	1.85
Cyperus rigidifolius	*Cyperaceae*	29	1.83
Sphaeranthus suaveolens	*Asteraceae*	30	1.83
Abutilon mauritianum	*Malvaceae*	31	1.82
Cassia mimosoides	*Leguminosae*	32	1.82

Table 3.10: Species list summary showing rank abundance and families of plants found at Nalogomon Dam in Nairobi National Park

Nalogomon Dam Plant Species Name	Family	Rank Abundance	Log (Sum Abundance
Hyparrhemia rufa	*Poaceae*	1	3.01
Ischaemum branchyatherum	*Poaceae*	2	2.74
Typha domingensis	*Typhaceae*	3	2.30
Themeda triandra	*Poaceae*	4	2.01
Cyperus dives	*Cyperaceae*	5	1.90
Acacia gerandii	*Leguminosae*	6	1.87
Scutia myrtina	*Rhamnaceae*	7	1.83
Bothrochloa insculpta	*Poaceae*	8	1.81
Rhus natalensis	*Anacardiaceae*	9	1.76
Orthosiphon sp	*Lamiaceae*	10	1.76
Rhynchosia minima	*Leguminosae*	11	1.72
Becium obovatum	*Labiatae*	12	1.72
Aristida adoensis	*Poaceae*	13	1.71
Asystasia laticapsula	*Acanthaceae*	14	1.64
Ocimum kilimandscharicum	*Lamiaceae*	15	1.63
Aspilia mossambicensis	*Asteraceae*	16	1.62
Setaria sphacelata	*Poaceae*	17	1.61
Stachys argillicola	*Lamiaceae*	18	1.61
Gomphocarpus fruticosus	*Asclepiadaceae*	19	1.58
Leucas nepetifolia	*Lamiaceae*	20	1.48
Vigna sp	*Fabaceae*	21	1.38
Conyza sumatrensis	*Asteraceae*	22	1.34
Cymbopogon caesius	*Poaceae*	23	1.34
Cynodon dactylon	*Poaceae*	24	1.32
Kalanchoe lanceolata	*Crassulaceae*	25	1.23
Solanum incanum	*Solanaceae*	26	1.2
Tagetes minuta	*Asteraceae*	27	0.85
Thunbergia alata	*Acanthaceae*	28	0.78

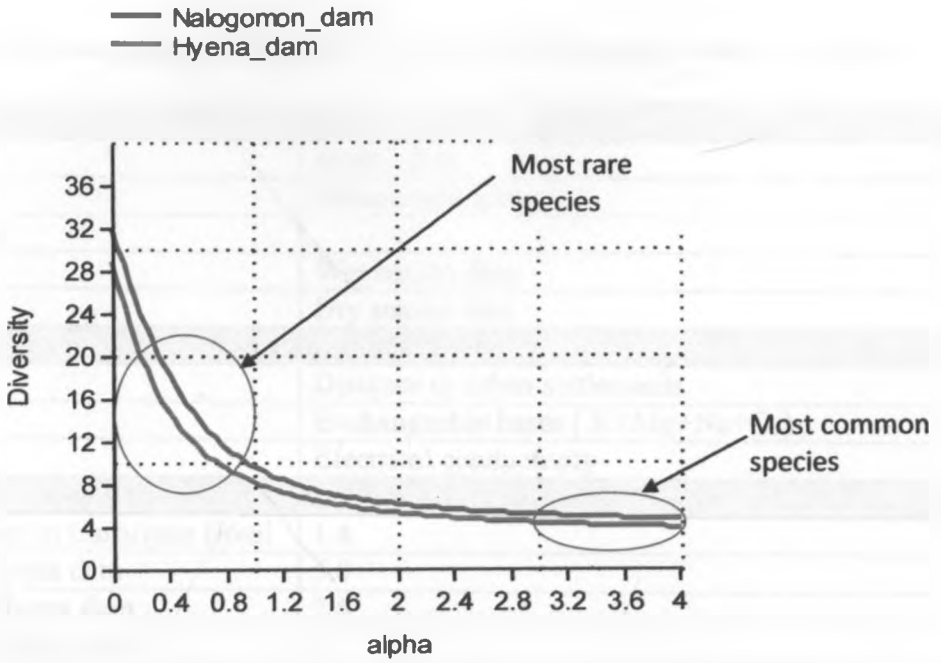

Figure 37: Diversity ordering of two wetlands; Nalogomon and Hyena dams in Nairobi National Park (Diversity alpha range 0 - 2 shows rare species, 2 - 4 common species). *(Note: Hyena Dam has a higher profile (the line in the diagram) than Nalogomon Dam, therefore the diversity ordering is Hyena Dam > Nalogomon Dam).*

3.6 Environmental gradients in the wetland soil/sediment and water

Principal Components Analysis (PCA) and Canonical Correlation Analysis (CCA) were used to identify important environmental gradients in the wetlands at Hyena and Nalogomon study sites. Table 3.11 shows how much of the variation in the water and soil/sediment data is explained by PCA and CCA. Table 3.12 shows the most important variables that explain the variation

Table 3.11: Codes and parameters used in PCA and CCA ordination analysis and plots

Wetland codes	
H	Hyena dam
N	Nalogomon dam
Season codes	
W	Wet season data
D	Dry season data
Parameter codes	
Dist	Distance to urban settlements
Bases	Exchangeable bases (K+Mg+Na+Ca)
EC	Electrical conductivity
Distance to urban settlements of sample sites (km)	
H1 - Hyena next to Carnivore Hotel	1.4
H2 - East of Hyena dam	5.0
H3 - West of Hyena dam	2.5
H4 - South of Hyena dam	5
N1 - North of Nalogomon dam	2.8
N2 - East of Nalogomon dam	9
N3 - West of Nalogomon dam	4.3
N4 - South of Nalogomon dam	4.7

Note: Distances to urban settlements were determined using GPS positions obtained in field.

Table 3.12: Environmental variation explained by the first 7 PCA axes in water and soil/sediment

	Water			Soil/sediment		
Axis	Eigenvalue	% of Variance	Cumulative % of Variance	Eigenvalue	% of Variance	Cumulative % of Variance
1	3.13	44.68	44.68	3.02	43.13	43.1
2	1.78	25.43	70.12	1.89	27.05	70.2
3	0.98	13.94	84.06	1.00	14.27	84.4
4	0.63	9.04	93.10	0.58	8.34	92.8
5	0.27	3.81	96.90	0.28	3.99	96.8
6	0.16	2.32	99.22	0.16	2.29	99.1
7	0.06	0.78	100.00	0.07	0.94	100.0

Table 3.13: Eigenvectors of the first 3 PCA axes in site wetland and soils.

	Water			Soil/sediment		
Variable	1	2	3	1	2	3
EC	0.21	**0.57**	**0.47**	0.42	-0.10	0.19
P	-0.41	0.24	**0.46**	**0.54**	0.02	0.06
Cu	**-0.52**	0.04	-0.14	**0.52**	0.12	-0.14
Zn	-0.45	0.16	-0.46	0.13	-0.32	**-0.85**
Mn	**-0.46**	-0.09	0.45	-0.07	**0.67**	0.05
Distance to urban settlement (Dist)	0.25	**0.54**	-0.16	-0.43	-0.40	0.08
Exchangeable Bases	0.20	**-0.54**	0.33	0.23	**-0.52**	**0.46**

Note: The first 2 variables with highest eigenvectors in each axis are highlighted.

The first 3 ordination axes, which are considered the most important, extracted 84.06% of the total variation (Table 3.11), and in PCA this is good. Copper a heavy metal associated with pollution and manganese and also linked with fossil fuels and oils, accounted for the highest variation in the wetland waters (Table 3.13).

Phosphorous an element that strongly influences diversity in grasslands and copper that is associated with pollution contributed to the highest variation in the wetland soil/sediment (Table 3.13).

3.7 Environmental gradients

PCA showed that in 12 parameters (physico-chemical properties and distance to settlements) analysed accounted for over 84% of the variation in both wetland waters and soils was accounted for. This indicated that important variables responsible for variation in characteristics of wetland waters and soils were assessed.

In wetland waters, Cu and Mn contributed most to variation that was related to distance to nearest urban settlements depicted in second axis. This means that the concentration of the two elements increased as distance to settlements decreased. Elements Cu and Mn are pollution indicators and their increased concentration in the wet season in

wetlands close to urban areas could be due to run-off or storm waters from the settled areas finding its way into the wetland.

Urban storm water run-off is increasingly being recognized as a substantial source of pollutants to receiving waters (Davis *et al.,* 2001). Some sources of the heavy metals such as lead, copper, cadmium, and zinc include building siding and roofs; automobile brakes, tyres, and oil leakage; and wet and dry atmospheric deposition. For copper, building siding and vehicle brake emissions are particularly important (Davis *et al.,* 2001). Other studies have also shown strong circumstantial evidence that manganese pollution occurs along with lead in city environments and is related to traffic density with the most likely sources being automobile exhausts (Joselow *et al.*, 1978).

On the other hand P accounted for one of the highest variation for elements in soils of the wetlands. Omari (2008) found that P contributed to the highest variation in soils characteristics across a wide variation of vegetation types in Nairobi National Park. While this study showed the same was true for wetland soils it further highlighted the importance of Cu and Mn. It can therefore be said that while P remains the primary contributor of variation in wetland soils they are secondarily modified by Cu and Mn, indicating the effect of water pollution on soils especially close to the urban settlements.

The PCA results therefore show that increasing levels of pollutants along a gradient of distance to urban settlements was the most important determinant of variation in wetland water characteristics. On the other hand, soil P like for soils in other ecosystems of the park was the primary determinant of variation but was secondarily modified by pollutants.

3.8 Factors influencing plant species distribution

From the CCA results, 3 groups of species as related to environmental gradients were separated, namely 1) species with highest abundance in sites close to urban settlements and most polluted areas, 2) species furthest from urban settlements and least polluted mainly Nalogomon wetland, and 3) species with highest abundance around Hyena dam which are close to urban settlements. CCA identified this separation of species to be principally related to gradients in distance to urban settlements, copper, phosphorous and exchangeable bases. Critically P and Cu varied along the distance gradient, being highest closest to urban settlements mainly the Hyena wetland.

A previous study by Omari (2008) demonstrated that high concentrations of soil P was strongly associated with distribution of non-indigenous and invasive species such as *Ricinus communis, Argemone mexicana, Solanum incanum, Tagetes minuta, Opuntia exaltata, Opuntia ficus-indica, Caesalpinia decapetala* in Nairobi National Park ecosystem. In the present study, the invasive species *Latana camara* was found in areas of highest P and closest to urban settlements where there was also the highest disturbance. Disturbances were noted just outside the park fence and included soil disturbance during the construction of roads and estates, and dumping of the excavated soil. Disturbances including overgrazing and soil disturbance play a critical role in the proliferation of invasive species through alteration of resource supply that is facilitated influx of resources such as soil nutrients or unusually heavy rains (Mworia *et al.*, 2008).

Pollution can influence species distribution with certain species being indicators the phenomenon. Indicators of pollution can be placed into several categories among them; "detectors" which are species occurring naturally in the area which show responses to

increased pollution, and 'exploiters' species though not occurring naturally in the area their presence indicates probability of pollution. In the present study, some species associated with the most polluted areas included; *Lantana camara, Indigoffera errecta* and *Dychoreste radican.* It was, however, beyond the scope of the study to determine if the plant species did respond to pollution.

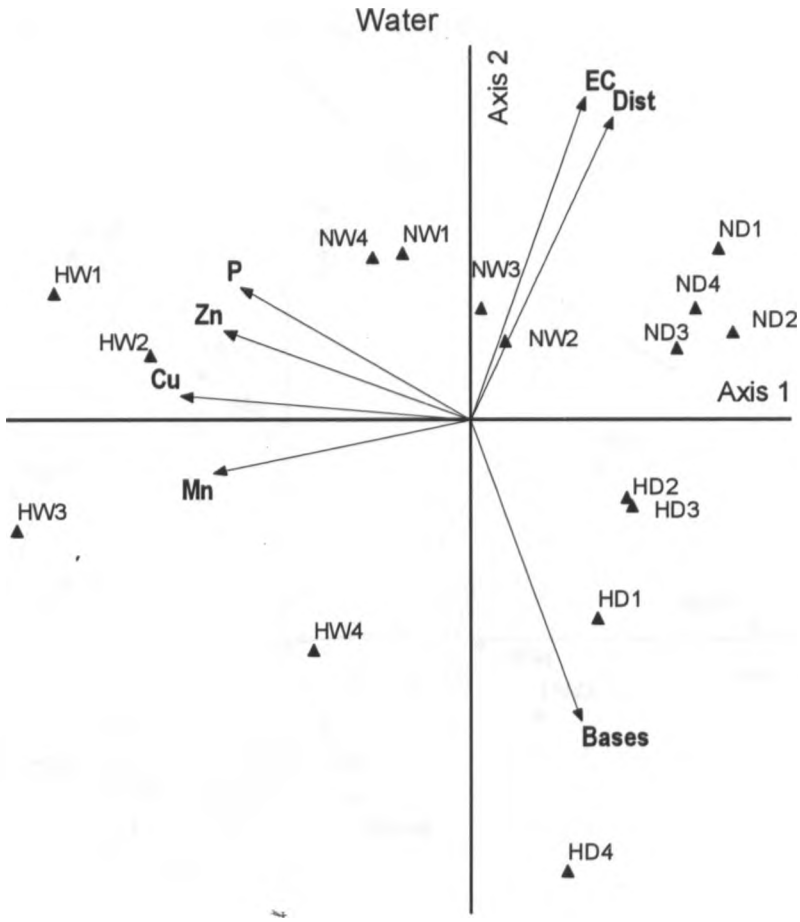

Figure 38: Principal Component Analysis (PCA) based on a correlation matrix of 7 water variables collected over 2 seasons in Hyena and Nalogomon study sites. The key to species codes are shown in appendix 5.

The PCA ordination plot (Figure 38) shows that waters at Hyena Dam experienced greater seasonal variation in mineral concentrations than those at Nalogomon Dam. This

variation is characterized increased concentrations of Cu, Mn and Zn all indicators of pollution in wet season especially in sites close to urban areas, i.e. HW1 and HW2 in the upper left quarter of the biplot. In the dry season waters of Hyena are characterized by high concentrations of exchangeable bases (HD4, HD1, HD3 and HD2 in the lower right quarter).

In contrast waters of Nalogomon wetlands do not vary strongly between seasons with most samples falling in the upper right quarter.

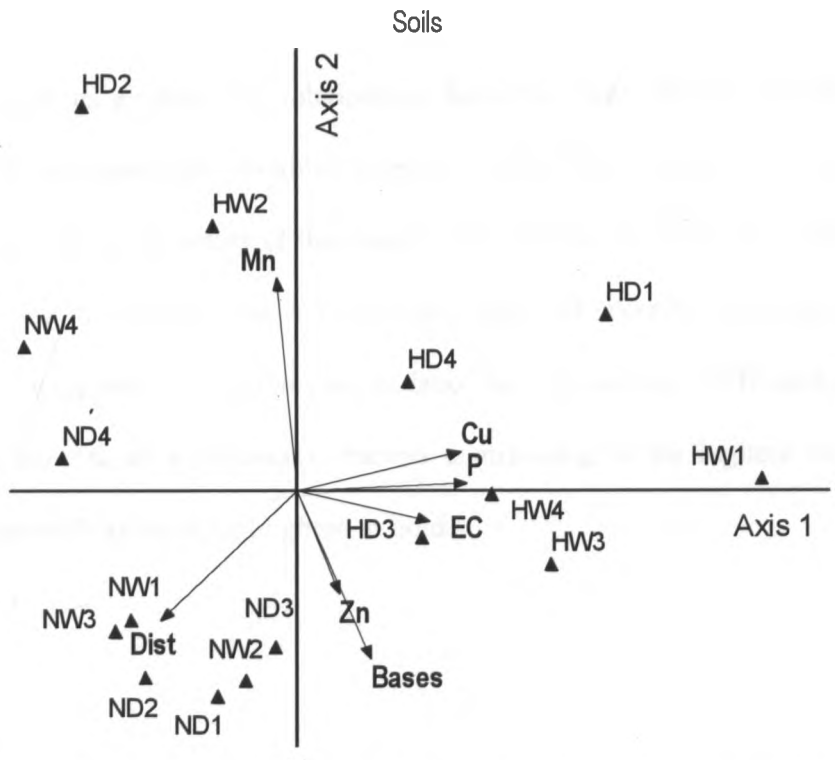

Figure 39: Principal Component Analysis (PCA) based on a correlation matrix of 7 soil/sediment variables collected over 2 seasons in Hyena and Nalogomon study sites. The key to species codes are shown in Appendix 4.

The PCA ordination plot on the wetland soil/sediment (Figure 39) shows a clear gradient that separates Hyena and Nalogomon wetland soil/sediment, that is, a distance to

urban settlements gradient. Nalogomon soil/sediment which are at the greatest distance from urban settlements (lower left quarter) are characterized by low Cu, P and EC while Hyena Dam soil/sediment at the opposite end of this gradient (HD4, HD1, HW1) have high concentrations of the same. It is also observed that seasonal variation in soil/sediment characteristics is less pronounced than in water – wet and dry season position of sampling sites are close.

3.9 Factors influencing plant species distribution at Hyena and Nalogomon wetlands study sites

CCA was used to explore the relationship between plant species distribution in the wetlands and environmental variables assessed. Table 3.14 presents two sets of outputs from CCA analysis, a summary of the statistics that shows the strength of the relationship between species distribution and environmental data and secondly environmental factors that explain the highest variation in species data. The correlations coefficients shown in the table above are interset correlations. Factors contributing to the highest variation hence characterizing each axis are highlighted in bold.

Table 3.14: The influence of environmental and land use variables on plant species distribution and composition as extracted by CCA

Variance in species data	Axis 1	Axis 2	Axis 3
% of variance explained	49.9	16.4	10.8
Cumulative % explained	49.9	66.3	77.1
Pearson Correlation, Spp-Envt*	0.999	0.884	0.854
Kendall (Rank) Corr., Spp-Envt	0.913	0.657	0.712
Eigenvalue	0.698	0.229	0.151
Variable			
Electro-conductivity (EC)	-0.388	0.135	0.377
Phosphorous	-0.631	**0.446**	0.326
Copper	**-0.714**	0.407	-0.089
Zinc	0.035	-0.066	-0.276
Manganese	-0.383	0.043	-0.313
Distance to urban settlements (Dist)	**0.994**	0.066	-0.031
Exchangeable Bases (Bases)	0.215	0.172	**0.539**

The extracted variation in species composition was largely explained by the environmental factors assessed as shown by the high Pearson correlation coefficient and eigenvalue Distance to urban settlements and copper levels characterize or explain highest variation the first axis which in turn explains the highest variation in plant species composition. This is an axis reflecting pollution. The second axis is characterized by phosphorous and last by exchangeable bases.

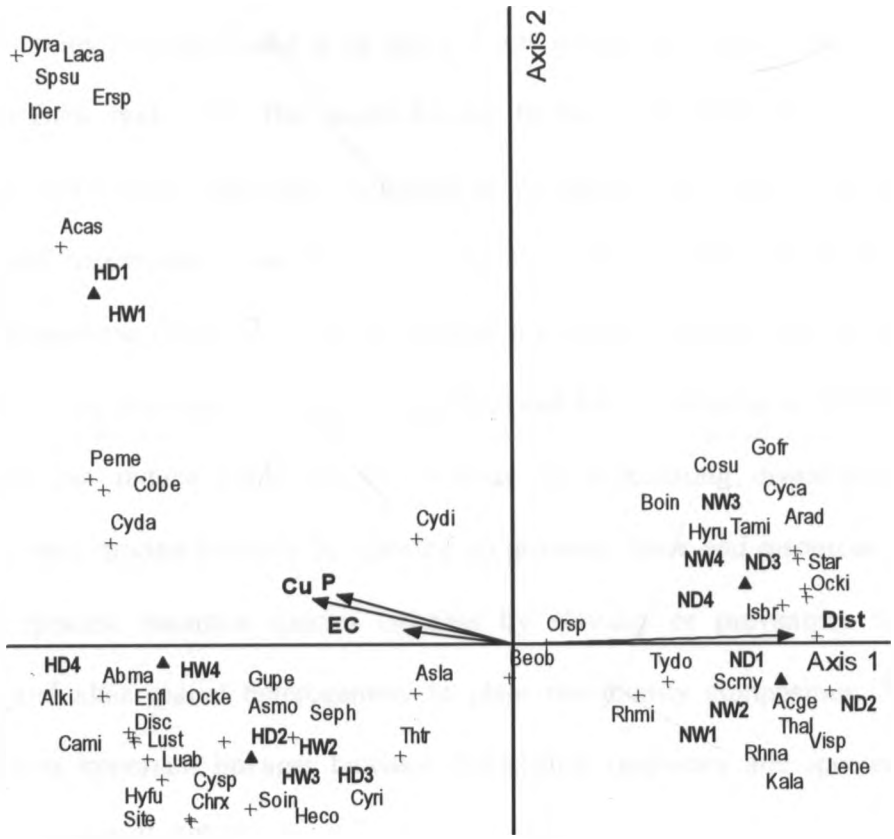

Figure 40: CCA ordination diagram showing the distribution of plant species as influenced by environmental factors assessed. The key to species codes are shown in Appendix 4.

The first CCA axis characterized by a gradient of distance from urban settlements and levels of Cu, P and EC separated species distribution into 2 broad groups: those that have higher abundance in Nalogomon wetlands on the right half of the CCA biplot and those that have higher abundance in Hyena wetlands on the left half (Figure 40). Also of interest is the distribution of species in Hyena wetlands; the upper left quarter depicting the most heavily polluted area with lowest distance to urban areas i.e. close to carnivore. This site was dominated only by a few species and importantly the presence of *Lantana camara* an invasive species rapidly becoming a threat to conservation areas in Kenya.

3.10 Plant species diversity and composition

Hyena Dam study site was found to be move divers in species composition compared to Nalogomon Dam study site. This could be due to the disturbance caused by wildlife overgrazing and human activities. Competitive exclusion, disturbance processes, and environmental heterogeneity are three Key determinants of plant species diversity in terrestrial ecosystems (Connell, 1978). Competitive exclusion reduces species diversity as strong competitors first suppress lesser competitors and later drive them to local extinction. Disturbances can reduce plant species diversity by eliminating disturbance-sensitive species, increase species diversity by opening up growing space and resources for use by colonizing species, maintain species richness by slowing or preventing competitive exclusion, and alter spatial heterogeneity in plant community composition. Ecological theory predicts important linkages between disturbance frequency and species diversity (Grime, 1973; Connell, 1978)

3.11 Conclusion and Recommendations

3.11.1 Conclusions

Human activities, for example pollution leading to contaminated waters, could have great impact on wetlands and hence on wildlife conservation in general. It was concluded from the data that pollution coming from human settlements around the park flow into surface waters of Hyena Dam. It can then be seen that monitoring of water quality is the first step that can lead to better management and conservation of wetland ecosystems. Management of the two wetlands should be aimed at conservation of their habitats by suitably maintaining the physico-chemical quality of water within acceptable levels. The

information and observation of this research will be very useful in formulating management policies on future use of wetlands at Nairobi National Park especially on conservation of wildlife.

3.11.2 Recommendations

The following recommendations can be made out of the results of this study:

1. There is need for long term monitoring of effluents from the urban settlements into the wetlands of Nairobi National Park.
2. There is need to monitor the effects of heavy metal pollution on animals using water from wetlands in the Nairobi National Park.
3. There is need to monitor proliferation of aquatic weeds in the wetlands of Nairobi National Park.
4. There is need for conservation of wetlands in the Nairobi National Park as they are known to provide vital ecosystem goods and services.

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APPENDICES

Appendix 1: ANOVA on soil/sediment physico-chemical properties

Factor	Sum of Squares	df	Mean Square	F value	Significance level
pH	1.420	1.000	1.420	3.223	0.083
EC	71678.445	1.000	71678.445	2.557	0.120
N	0.023	1.000	0.023	3.284	0.080
P	18701.297	1.000	18701.297	11.158	0.002*
K	248664.098	1.000	248664.098	4.101	0.052
Ca	1571733.473	1.000	1571733.473	1.202	0.282
Mg	446944.942	1.000	446944.942	9.356	0.005*
Na	672408.557	1.000	672408.557	4.730	0.038*
Cu	31.205	1.000	31.205	12.452	0.001*
Zn	28.673	1.000	28.673	0.264	0.613
Mn	3528424.183	1.000	3528424.183	3.300	0.079
Fe	81870.811	1.000	81870.811	0.015	0.904
SO_4	22875.001	1.000	22875.001	6.184	0.019*

**Significantly different at 5% probability level*

Appendix 2: ANOVA on water physico-chemical properties

Factor	Sum of Squares	df	Mean Square	F value	Significance Level
pH	0.515	1.000	0.515	2.790	0.105
EC	16698.781	1.000	16698.781	0.736	0.398
N	0.002	1.000	0.002	0.326	0.574
P	0.415	1.000	0.415	1.432	0.242
K	2.426	1.000	2.426	0.005	0.945
Ca	4.000	1.000	4.000	0.063	0.803
Mg	3.144	1.000	3.144	0.826	0.371
Na	583.419	1.000	583.419	0.530	0.472
Cu	0.000	1.000	0.000	5.084	0.074
Zn	0.000	1.000	0.000	0.055	0.823
Mn	20.021	1.000	20.021	33.777	0.000*
Fe	49.784	1.000	49.784	0.146	0.706
SO_4	114.610	1.000	114.610	5.210	0.030*

**Significantly different at 5% probability level.*

Appendix 3: ANOVA on chemical properties of plant tissues analysis

Element	Sum of squares	df	Mean Square	F	Significance Level
N	14.873	1.000	14.873	7.646	0.009*
P	0.185	1.000	0.185	5.672	0.023*
K	0.576	1.000	0.576	0.482	0.492
Ca	0.166	1.000	0.166	1.596	0.216
Mg	0.005	1.000	0.005	1.351	0.254
Na	0.003	1.000	0.003	0.013	0.911
Fe	0.219	1.000	0.219	0.968	0.333
Mn	0.013	1.000	0.013	0.157	0.695

**Significantly different at 5% probability level*

Appendix 4: General list of plant species found at the two study sites

Species name	Species name
Abutilon mamitianum	*Hypoestis fuskalii*
Acacia gerandii	*Indigofera errecta*
Achyranthus aspera	*Ischaemum branchyatherum*
Alasea kilimandscharicum	*Kalanchoe lancestata*
Aristida adoensis	*Lantana camara*
Aspilia mossambicensis	*Leucas nepetifolia*
Asystasia laticapsula	*Ludwigia abyssinicas*
Becium obovata	*Ludwigia stolonifea*
Bothrochloa insculpta	*Ocimum kenyensis*
Cassia mimosoides	*Ocimum kilimandscharicum*
Chloris roxburghiana	*Orthesiphon sp*
Commelina benghalensis	*Peneisetum mezianum*
Conyza sumatrensis	*Rhus natalensis*
Cymbopogon caesius	*Rhychosia minima*
Cynodon dactylon	*Scutia myrtina*
Cyperus dives	*Setaria sphacelata*
Cyperus rigidifolius	*Sida termicarpa*
Cyperus sp	*Solanum incanum*
Digitaria scalarum	*Sphaeranthus sueveleous*
Dychoreste radican	*Stachys argillicela*
Enhydra fluctuana	*Tagetes minuta*
Eragrostis sp	*Themeda triandra*
Gomphocerpus frutiçosus	*Thunbergia alata*
Gunnera perpensa	*Typha dominfensis*
Heteropogon contortus	*Vigna sp*
Hyparrhemia rufa	